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SYSTEM COST ANALYSIS: A MANAGEMENT TOOL FOR DECISION MAKING

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ABSTRACT

This document presents a generalized, integrated conceptual approach to the major steps involved in estimating the costs of a military system. The approach is generalized in the sense that the document identifies the common methodological problems and tasks involved in costing all military systems. The approach is integrated in the sense of discussing the entire process of costing a system from beginning to end and in showing the methodological relationships of each sequential step to preceding and subsequent steps. The approach is conceptual in the sense that fundamental principles are stressed as opposed to a catalog of resource costs and estimating relationships or a case book detailing the specific procedures used to cost particular systems in the past.

Notwithstanding its conceptual orientation, the approach in this study is task oriented in the sense that discussion centers around such highly practical questions as the following: what an analyst should learn about the client's intended application of the estimate and about the details of the system he is to cost before he begins the costing task itself; the criteria an analyst can use to help him realize the greatest benefit from the limited time he normally has available to make the estimate; the types of activities and resources he should cost and in what detail; the types of data he should seek as a basis to cost such activities and resources, and the sources from which he should try to collect these data; how he should proceed to evaluate and synthesize his data inputs to arrive at his system cost estimate; how he should present the details of his findings so that they will be most meaningful to his client and not be misinterpreted.

REVIEW AND APPROVAL

This technical report has been reviewed and is approved.

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PREFACE

This document integrates and provides a status report covering the conceptual research in system cost methodology that The MITRE Corporation has accomplished during the last four years.

In April of this year an initial draft of this study was circulated among the staff of MITRE's Systems Analysis Department (D-53) for review and comment. The writer wishes to acknowledge and to express his deep appreciation for the many, valuable comments received from the following D-53 staff who reviewed and commented on the initial draft: Frank W. A'Hearn, Ahti E. Autio, Joseph M. Cappelletti, Richard M. Durstine, Charles S. Enright, John A. Evans (now with MITRE's Information Sciences Department), Harold Glazer, Robert L. Hamilton, Thomas J. Jannsen, Eugene D. Lundberg, William Marcuse, James R. Miller, III, Lee R. Morris, William C. Morsch, Robert L. Murphy, Herbert B. Roseman, David F. Votaw, Jr., Carter F. Wolfe.

The writer is especially indebted to Dr. Norman Waks, Special Assistant for Economics and Systems Acquisition to MITRE's Vice President for Technical Operations, and to Mr. Eugene D. Lundberg, Head of MITRE's Systems Analysis Department, not only for their generous administrative support and technical counsel, but also for the personal interest they have maintained in this undertaking from its inception through its present formulation.

Footnotes in this document are used, almost exclusively, to identify source references. To facilitate reading, these footnotes have been consolidated, with a few rare exceptions, at the end of each chapter rather than at the bottom of the page on which the reference is cited. The applicable page in the text to which the footnote applies is identified in the right hand margin of the footnote page.

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CHAPTER 1

SOME BASIC PROPOSITIONS

1.1 Purpose

This paper aims to present a generalized, integrated, conceptual picture of the major steps involved in costing large-scale military systems. The approach in this study is generalized in the sense that it seeks to identify the common methodological problems and tasks involved in costing all large military systems. In fact, the methodology seeks to be even more generalized in that it also aims to be potentially applicable to estimating the costs of modern space systems and other complex public or private civilian undertakings (see pp. 19-20).

The approach seeks to be integrated in the sense of discussing the entire process of costing a system from the beginning of its life cycle to the end and in showing the methodological relationships of each sequential step to preceding and subsequent steps.

The approach is conceptualized in the sense that fundamental principles are stressed as opposed to a catalog of resource costs and estimating relationships or a case book detailing historically the specific procedures used to cost particular systems in the past. In other words, the document does not provide a detailed costing "cook book", a self-contained set of how-to-do-it costing algorithms. Questions of why and when to use a given costing procedure are usually accorded equal attention with questions of how to use the procedure.

Finally, this document is an interim report. Illustrative of material to be covered in a subsequent edition are the following:

a. Fuller and more numerous examples will be provided to illustrate some of the theoretical concepts set forth in the present study. These examples will draw from case histories, from advanced planning studies of particular systems, and from actual system cost experiences to illustrate the relevance and interface of the concepts outlined in this document.

b. A subsequent edition will also make use of extensive graphic and visual material to supplement the almost purely verbal exposition of the present document.

c. A subsequent edition, perhaps a companion study, will provide a data-base complement that will facilitate the use of the methodological concepts set forth in this document.

d. A later edition or study will consider in more detail a matter only lightly touched on in the final chapter of the present study; namely, the potentialities and limitations of system analysis, including cost analysis, as a tool of decision making.

The paper is directed to three types of audiences. First, it aims to be useful as a training aid for newly recruited members of the system costing profession. Second, it is addressed to the clients of the system cost analyst. By acquainting them with the problems that confront the cost analyst, it is hoped that they will better appreciate both the potentialities and limitations of the cost estimate. Third, it is hoped that the document will be helpful to professional cost analysts, including system cost methodologists, as a frame of reference for developing new and better methods of estimating military system costs in the future.

1.2 Basic Terms

Resource: A resource, as defined here, is any limited supply, natural or manufactured material or agent useful either directly or indirectly when employed in combination with other materials or agents to satisfy a personal or social objective. Examples of resources as used in this document: equipment, buildings, personnel services, etc.

Cost: A cost is a resource drain, the commitment of a valuable, limited-supply,multi-use material or agent to a specified use. The concept of cost is both basic and complex. It will be discussed frequently throughout this document, expecially in Chapters 2 and 8.

Effectiveness: Effectiveness is a value concept. As used here, it represents the value or worth placed upon designated attributes of military performance such as the value of a Mach 3 speed aircraft or of the fifteen-minute warning time provided by a radar system.

System: A system is the sum total of human and material resources, including the procedures required to coordinate their functioning, employed to satisfy a designated mission or objective. For instance, System 416L (SAGE) basically consists of designated types and quantities of buildings, equipment, and people directed to providing warning of an enemy aircraft attack on the Continental United States and Canada.

Decision Maker: A person or agency responsible for choosing among several or numerous alternative means of accomplishing a given goal. The term decision maker, as used here, is almost synonymous with the term manager. The term "decision maker" is preferred to the term "manager" because the term "manager" historically connotes administrative responsibility that may or may not exist in certain contemporary decision making situations.

1.3 The Importance of Cost

1.3.1 The Role of the Cost Estimate

A cost estimate is properly viewed as one of the tools that military planners and systems designers can invoke to help select systems that will maximize the effectiveness of the military forces. This view contrasts with the position, more widely held five years ago than it is today, that the cost estimate is principally a constraint or club wielded by comptrollers to limit the effectiveness of the military force.[1] (See below)

The role of the cost estimate in helping, rather than hindering, the military planner to maximize the effectiveness of his forces rests upon a series of self-evident and generally accepted propositions. These propositions are derived from classical economic principles and apply with equal force in any decision situation whether one adopts the perspective of a private family seeking to spend its income wisely, a corporation executive trying to strengthen the total competitive position of his company, a university president trying to match his plans and programs to his resources, or a military planner striving to maximize the effectiveness of his military forces

1.3.2 Multiplicity of Goals

The first proposition, referenced above, is that men and organizations in all walks of life have a multiplicity of goals, missions and objectives that they desire to satisfy.

1.3.3 Scarcity of Resources

The second proposition has two parts. First, resources must be expended -- costs incurred -- to carry out the programs drafted to meet the multiple objectives referenced above. Second, whatever the context,

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Footnotes related to each chapter are described at the end of that chapter, with certain significant exceptions which are incorporated in the text.

resources are scarce in the sense that the total demand for resources usually outstrips the total supply of resources. In other words, there are normally unfilled demands; for all practical purposes, a decision-maker seldom has sufficient resources to carry out fully all of the programs that he regards as legitimate and useful.

1.3.4 Opportunity Costs

Since considering all missions or objectives in toto the demand for resources exceed their supply, it follows that every dollar or unit of resources committed to one use means one less dollar or unit of resources available elsewhere. In other words, there is an "opportunity cost" -- an opportunity lost to satisfy some other legitimate objective elsewhere -- associated with using limited supply, multi-use resources to satisfy one want or objective rather than another.

1.3.5 Alternative Means To An End

A fourth proposition is that there are always several or numerous different ways of satisfying each of the competing goals or missions that a decision-maker has. This is as true whether the context is that of a private family planning to meet its requirements for shelter, transportation, or higher education as it is of a military planner seeking to provide a capability for warning against an enemy attack or an effective counter-attack capability.

1.3.6 Different Resource Requirements

Different system alternatives for meeting a given objective provide different efficiencies (different outputs per unit input) in the way they use available resources. Consequently, the costs of attaining a specified or equivalent standard of effectiveness in any given mission area varies (sometimes greatly) from system alternative to system alternative.

1.3.7 Cost As A Criterion

Taking as generally valid each of the preceding propositions, comparative costs automatically assume importance as one of the criteria that a decision-maker interested in maximizing his effectiveness in several mission areas, should consider in selecting among system alternatives. Since every dollar or unit of resources committed to one mission means one less dollar or unit of resources, and hence potentially less effectiveness, available for some other mission, a decision-maker who incurs greater costs than necessary in order to attain a specified or equivalent standard of effectiveness in one area, wastes resources and in so doing automatically reduces the effectiveness of his total forces.

One implication of this "opportunity cost" approach to system decision-making is a rejection of the notion that an intrinsic value can be assigned to achieving any performance level that is independent of the costs of achieving that goal. Stated affirmatively, the opportunity cost approach to system decision making contends that in assessing the value of a proposed, more costly increase in performance capability in one mission area, one must consider the consequences of a degraded performance level in some other mission area that will result from such a diversion of resources. To illustrate, it is impossible to decide wisely whether we should adopt a new system that would provide a ten per cent increase in our offensive striking power solely by considering the additional damage such an increment in striking power would enable us to inflict upon the enemy. Whether this increased striking power-- whether this increased capability to damage the enemy -- would actually enhance our total military strength compared to that of our enemy would depend upon the quantity of resources required (the costs) to achieve that ten per cent increase in striking power and the effect such diversion of resources would have on the level of performance in other important mission areas. When resources are scarce -- as they always are -- the answer to the above question would depend upon whether the opportunity costs of the ten per cent increase in striking power were a 1%, a 10%, a 50% or a 99% relative degradation in some other vital military mission, such as defensive capability or some other important national objective such as economic assistance to undeveloped countries.

The same comparative costs trade-off considerations, of course, apply when a military planner or system designer is making intra-system configuration decisions relative to the amount of effectiveness he will see in the realm of each of a given system's performance characteristics.

1.3.8 Cost/Effectiveness Rationale

In setting forth the logic of the "cost as a decision making criterion", deliberate care has been taken to use the words "specified" or "equivalent" level of effectiveness. This qualification is important because it suggests another important point. The use of cost as one of the decision making criteria does not necessarily imply a preference for the lowest cost system alternative. (A $2 pair of shoes may be a more costly means of providing for one's footwear needs than is a $20 pair). Cost relative to effectiveness is the important reference, and the lowest cost alternative is favored only in terms of a specified or equivalent level of effectiveness for the various alternatives. Hitch and McKean have argued persuasively for the concurrent consideration both of cost and effectiveness, for a cost/effectiveness approach, in making system analysis decisions. They have tried to make their point clear by the following analogy:

> Strategy and cost are as interdependent as the front and rear sights of a rifle One cannot assign relative weights to the importance of the positions of the front and rear sights It does not make sense to ask the correct position of the rear sight except in relation to the front sight and the target. Similarly one cannot economize except in choosing strategies (or tactics or methods) to achieve objectives. The job of economizing, which some would leave to the budgeteers and comptrollers, cannot be distinguished from the whole task of making military decisions.[2]

This question of the inextricable relation between choosing objectives and comparative costs will be briefly discussed again in Chapter 10 when the use of the cost estimate as a decision making tool is resumed.

In summary, the universal prevalence of resource limitations, the multiplicity of goals and missions, the ever present possibility of using alternative means or systems involving different resource requirements to meet each specified goal, all give rise to an opportunity cost in using resources one way vs another. The net result is that the question of comparative cost takes on critical importance to a military planner interested in maximizing the effectiveness of his total forces.

1.4 <u>The Importance of Reliable Costing</u>

1.4.1 <u>The Common Sense Argument</u>

Simple logic or common sense would dictate that if comparative cost is to be used as one of the criteria in choosing among system alternatives, it is important that these costs be reliable. In other words, comparative cost would be a useful and valid criterion for selecting among system alternatives only if the cost estimates measure with tolerable accuracy the actual costs they are intended to measure. If these estimates are grossly inaccurate, they will serve as a highly misleading decision making criterion.

1.4.2 The Consequences of a Costing Error

Untoward consequences of a serious error in a cost estimate can be felt in the case either of a serious overestimate or underestimate. A serious overestimate can cause a decision maker to forego a good system because it appears to be too expensive. Or an overestimate can delay other projects by erroneously allocating too many resources to a particular project.

The most frequent and serious consequences of an error in costing occur, however, when the costs of a major system are grossly underestimated. This is true because historically most errors have been underestimates.[3] The consequence of a serious cost underestimate is normally either a retrenchment in the affected program or in some other important program. These readjustments in programs not only seriously erode the planned effectiveness of the total military force, they also cause a serious waste of national resources and frequently entail violent and prolonged dislocations in the economies of large regions of the country.

The crucial importance of minimizing such adjustments in programs and the resulting economic dislocations derives from the tremendously large resource investment the nation makes in military and space programs. The military and space industry is now one of the nation's largest industries, and Defense and NASA expenditures constitute roughly ten per cent of the United States gross national product and exceed the gross national products of all but a handful of other countries in the world.

In certain important areas, such as research and development, the magnitude of military programs is even more impressive. For instance, United States annual expenditures for all types of medical research, public and private combined, approximate $1 billion per year. On the other hand, research and development expenditures by the Department of Defense approximate $7 billion per year. Adding the R&D expenditures of the National Aeronautics and Space Administration and the Atomic Energy Commission to those of the Department of Defense increases the total federal R&D expenditures for national security purposes to approximately $13 billion.

An equally impressive picture is obtained if one considers individual systems. A landmark was reached in World War II when the nation undertook its first billion-dollar system, the Manhattan Project to develop the atomic bomb. By comparison, in 1962 it was authoritatively estimated that the Defense Department alone had twenty systems in various stages of development, each costing $1 billion or more.[4]

Summarizing, the development of modern military and space systems is perhaps basically the largest, most comprehensive series of ventures that man has ever undertaken and necessarily requires the expenditure of huge quantities of resources. However, since errors in estimating the resource requirements of these systems can have far-reaching repercussions not only on the effectiveness of our total military posture but also on the economic well being of the entire country, it is extremely important that increasingly reliable methods for estimating the costs of these systems be developed.

1.5 Why It Is Difficult To Cost A Military System

1.5.1 A Common Misconception

One of the common misconceptions of individuals having only a peripheral acquaintance with the system costing field is the notion that such costing is a relatively simple, straight-forward numbers game requiring a basically unsophisticated methodology. Fortunately, this judgment has been tempered in recent years by the serious difficulties that professionals in various disciplines have experienced in trying to accurately estimate an advanced system's cost.

There are many reasons why it is difficult, rather than easy, to accurately estimate such costs.

1.5.2 Interdisciplinary Knowledge

One reason is that the cost analyst must be conversant in several disciplines, not one. This can be explained by the fact that historically most serious errors in system cost estimates in the past have been traced to what has been called "configuration uncertainty". Stated differently, most costing errors have been due to the extreme difficulty of anticipating in the advanced planning stage of a system's development what types and quantities of resources will eventually be required to develop, acquire, and operate the system. If the cost analyst is to cope with configuration uncertainty, it is not sufficient that he be versed in accounting techniques, cost data sources, or even in the principles of economics.

There are many reasons why it is difficult to cope with configuration uncertainty. One is that the specification of the physical unit -- the resource definition of the system to be costed -- is a derived input and this derivation is a function of such elusive considerations as the nature of the enemy threat and the probable impact of technological progress.

In turn, each of these parameters from which the physical unit calculation is derived is highly unstable and very difficult to predict. Taking the matter of technology, for instance, the rate of technological change in the military and space field is the most rapid and volatile in our economy.

Finally, in the case of advanced systems costing the estimates must be projected five to fifteen years into the future. This time-frame in itself presents a prodigious undertaking if one compares it with that prevalent in other disciplines in which forecasting is practiced. For instance, economic activity forecasts, political forecasts, weather forecasts, and forecasts of fashion in clothes are usually restricted to a matter of several months, or at most, a year or two ahead.

1.5.3 Increasing Complexity

A related consideration that makes it very difficult to estimate the costs of military and space systems is the tremendous and increasing complexity of many of these systems. Complexity as defined here is taken to include not only the intricacy of the basic technology of these systems but also the manifold problems in keeping abreast of a rapidly changing technology. Various authorities have assembled objective evidence of this complexity. For instance, as compared to military systems of a decade or two ago or as compared to complex contemporary civilian undertakings, many military and space systems involve tremendous -- sometimes geometric -- increases in:

(1) the number of components involved. For instance, Admiral Rickover recently testified that a Polaris submarine contains 3,400 separate complicated pieces of equipment and that a Polaris submarine must carry 30,000 separate kinds of spare parts.[5]

(2) the closeness of the tolerances and reliabilities with which these components must perform.

(3) the number of different functions a given subsystem must perform.

(4) the accuracy with which these subsystem functions must be performed.

(5) the degree of interdependency involved and the closeness of the integration required among these subsystems and components.

(6) the variety and severity of environmental influences that must be confronted in such matters as temperature, pressure, altitude, humidity, sonic vibration, electromagnetic interference, cosmic particles, etc.

(7) the variety, sophistication, and quantities of resources required for its development and operation. For instance, modern military-space systems have involved a hitherto unheard of mobilization both in depth and in breadth of the academic and industrial worlds. For instance, new major professions and industries have been created specifically to cope with the tremendous technical problems associated with developing and operating these systems. Somewhat illustrative of this condition, J. F. Atwood, President of North American Aviation Co., recently stated that today the staff of his company has degrees in 175 different college majors whereas twenty years ago most of the company's staff was trained in one of four basic engineering specialities.[6]

Some inkling of the quantitative impact of this mobilization of scientific-technical resources can be gathered from an examination of the number of engineering man-hours required to develop a new system. In this connection whereas major systems two or three decades ago may have required several hundred-thousand engineering man-hours, some of the current more advanced systems require as many as 15,000,000 engineering man-hours to develop the system from design to initial operating capability.[7]

1.5.4 Difficult Data Problems

A major problem in securing reliable and relevant data is another condition that makes it very difficult to accurately cost a military or space system First, since the systems approach to military procurement is relatively new -- e.g., in the military electronic and space fields the oldest systems were introduced less than a decade ago -- there is a very small historical data base from which to project. This contrasts sharply with forecasting economic activity or population growth where the historical data base extends back for decades or, in some cases, for several centuries.

Second, for reasons that will be covered in Chapter 6, even this meager data base consists largely of heterogeneous observations having limited comparability with each other.

Third, because the rate of technological development is so rapid, cost analysts, to a much greater extent than is necessary in most disciplines, must supplement this meager and dubious historical data base with expert opinions, and the problems in eliciting and evaluating these opinions are legion.

Fourth, contributing to both the meagerness and the dubious quality of both the historical and expertise segments of the data base is the fact that much of the most relevant data are closely held rather than widely disseminated. Again, there are many reasons for this situation: national security reasons, the proprietary character of many industrial data, and, finally, the fact that the possession of a cost-estimating data base bestows upon the holder a competitive advantage over his rivals.

Fifth, although recent changes in Department of Defense regulations such as the discontinuance of cost-plus-fixed-fee type contracts, have promoted greater cost realism, inherent biases are associated with much of the available cost data. A substantial number of all cost estimates are developed by industrial sources to support a particular company's system proposal to a government agency or by a lower echelon government office to win approval for a program from a higher level government office in competition with other programs. Considering the competitive environment in which such estimates are developed, it is not surprising that they frequently lack the objectivity of a United States Census Bureau population count.

1.5.5 Difficult Conceptual Problems

Highly complicated conceptual problems sometimes make it hard to accurately estimate the costs of a military system. For instance:

a. The problem in defining "system cost" parallels the problem that economists and managering accountants have had for years in satisfactorily defining "profit" from either a social or a broad corporate perspective. One instance of this problem in defining system cost occurs in trying to devise suitable ground-rules for detecting and measuring the delayed and oblique costs associated with inherited assets, shared assets, fixed supply assets, salvage values, and spillovers (see Chapter 8).

b. There is a great problem in devising suitable criteria for objectively selecting one type of cost classification over another (see Chapter 4). Or similarly, there are problems in defining specific cost elements discretely and non-arbitrarily. For instance, in evolutionary, one-of-a-kind command and control systems, it is very difficult to distinguish between certain Research and Development and Investment Costs.

c. It is very difficult to establish criteria for comparatively evaluating and weighting heterogeneous objective and subjective data of different validities and relevancies that are to be used as inputs to a future estimate. (See Chapter 7.)

1.5.6 Lack of Formalized Methodology

The newness of the field and the consequent lack of a formalized methodology is a final reason why the task of estimating the cost of a military system is difficult. The cost analyst must, to such a large extent, rely on "his own devices". This lack of a formalized methodology is evidenced in many ways. No text book has ever been written on the subject in contrast to the literally hundreds of texts that have been written in the older disciplines such as economics, engineering or accounting or the dozens of books that have been written in such newer fields as operations research. In fact, except for the pioneering RAND literature, there is almost no "public" (generally available) literature on the subject. There is no journal in the field. As far as the writer knows, no civilian university gives a course on the subject. It is interesting that even the "Economics of National Security" course given by the Industrial College of the Armed Forces does not (1962) discuss the economics of costing or selecting a military system. Most of those working in the field were originally trained in a wide variety of other professional disciplines and they have literally learned by doing insofar as military system costing is concerned. There is one exception. During recent years RAND, the Air Force Institute of Technology, and Ohio State University have trained some Air Force personnel in this field.

1.6 The Basic Methodological Approach

1.6.1 The Scientific Method

The importance of reliable cost estimating to the military decision maker and the difficulties associated with accomplishing it have been outlined in the previous sections. This section will set forth the basic premis upon which, in the opinion of the writer, a better costing methodology must be built.

Simply and most generally stated, the path to progress in the field of costing lies in more extensive and intensive application of what is popularly termed the "scientific method". In this sense, basic methodology in system costing must follow the example set by every other field of learning for the last several centuries. The amazing progress that has been realized in other fields of knowledge, such as modern medicine and scientific management -- to mention two that touch the daily lives of everyone -- can be traced to the fact that the scientific method has been applied increasingly to problems in these areas.

Although the scientific method has many characteristics, its most distinctive quality is that it substitutes objectively verifiable evidence for authority as a criterion of validity. Operationally this means that the cost analyst must formalize his procedures explicitly so that his client or another analyst can independently replicate and verify his step-by-step methodology from beginning to end.

Alain C. Enthoven has perhaps best detailed the characteristics of this approach in recommending the application of the scientific method to system analysis problems in general:

> First, the method of science is an open, explicit, verifiable, self-correcting process. It combines logic and empirical evidence. The method and tradition of

> science require that scientific results be openly arrived at in such a way that any other scientist can retrace the same steps and get the same result. Applying this to weapon systems and to strategy would require that all calculations, assumptions, empirical data, and judgments be described in the analysis in such a way that they can be subjected to checking, testing, criticism, debate, discussion, and possible refutation.[8]

The reason why this method of science has historically been so successful in solving problems in many fields has been generalized by Jay Forrester as follows:

> The rapid strides of professional progress come when the structure and principles that integrate individual experiences can be identified and taught explicitly rather than by indirection and diffusion. The student can then inherit an intellectual legacy from the past and build his own experiences upward from that level, rather than having to start over again at the point where his predecessors began.[9]

Applying Enthoven's and Forrester's reasoning to the field of system costing, the scientific method should help the analyst to achieve greater success in accurately estimating the costs of a military system in two specific ways. One is that if an analyst disciplines himself to reach and support his cost opinions in a manner such that his methodology can be independently replicated by other observers, he is more likely to organize his data and conclusions in an internally consistent pattern. Second, and even more important, the opportunity for feed-back, which is essential to scientific progress in any field, is critically contingent upon relatively explicit, formalized procedures. If this analyst and other observers are to profit both by his mistakes and good insights, it must be clear as to how he reached his cost conclusions and why.

One of the problems with much of system cost analysis in the past has been that so much of the modus operandi has been unspecified even when overtures at formal documentation have been attempted. Under such circumstances when the analyst's estimating procedures are predominantly implicit, he finds it difficult to explain, even *ex post facto*, the reasons for his important decisions. He cannot determine why he went wrong because he had never thought out very carefully why he originally selected the particular cost estimating method that he used.

It must, of course, be realized that the terms objective methodology vs. subjective methodology reference an idealized dichotomy. In practice no methodology is ever likely to be wholly objective or subjective. However, the terms are useful in distinguishing the *direction* in which we are to move. In this sense the goal should be to impart more science and system to cost estimating and analysis rather than less, to make the undertaking more of a science and less of an art.

One final note. The desire to make the methodology of system cost analysis more scientific does not mean that reliance on judgment and expert opinion will be abandoned. Quite the contrary, in Chapter 7 it will be argued that increasing provision must be made to incorporate expert opinions as data inputs into the estimating procedure because such opinions are often more relevant than available historical data to a new system being costed. What is does mean is that judgment must be injected into the estimating, analysis, and decision processes in an explicit and deliberate fashion and not used indiscriminately as a cloak to camoflauge soft areas in data or evaluation.

1.6.2 Stress on General Method

It is a truism to state that no two systems are alike in configuration and operation or to state that significant differences also exist among certain broad classes of systems. For instance, certain electronic (command and control) systems differ from weapon systems in that the former tend to be one unit systems (like a headquarters command post), rather than many units systems (hundreds of B-52 airplanes). Command and control systems also tend to evolve from former systems rather than to make a complete departure from former systems as new weapon systems sometimes do. These design and functional differences also have certain implications for costing methodology such as the selection of criteria for distinguishing development from investment costs.

However, in most major respects comparable problems are confronted and comparable approaches should be taken whether the project is to cost one type of electronic system or another, an electronic system or a weapon system; an Air Force system or an Army, Navy or NASA system; a military system or a large unique civilian project such as the building of an Empire State Building, a New York World's Fair, a "Cleopatra"-type motion picture, or a major new industry in equatorial Africa.

From the point of developing a systematized methodology, this comparability of methodological problems and tasks has a real advantage in the possibilities it poses for a pooling of knowledge. Techniques that improve cost estimating and analysis methods for one type system will almost, per force, improve the state of the art for estimating and analyzing costs for other type systems.

The methodological analogy extends even further. As will be apparent from the discussion of later chapters, the methodological problems (both conceptual and empirical) that plague the system cost analyst are very similar to those that confront specialists in other disciplines such as economics in general, management science, sociology, psychology, operations research, managerial accounting, and even philosophy. Once again, this commonality of problems offers a fruitful opportunity for benefit from a study of the methodologies of kindred disciplines.

Proceeding from the premises set forth above, this paper will seek to identify and make explicit the separate but related tasks that an analyst has to perform and the types of decisions he has to make in costing <u>any</u> military or space system. In the process this paper will seek to pinpoint methodological pay-off tasks, i.e., tasks whose effective accomplishment have major import in deriving an accurate and useful system cost estimate. Illustrative of these tasks are the following:

a. What should an analyst learn about the system he is to cost and his client's intended use of the estimate before he begins costing?

b. What criteria should he use to determine the allocation of his limited time to different phases of the costing effort?

c. What types of activities and resources does he cost, and in what detail?

d. What types of data does he admit as inputs in order to cost the activities and resources identified in c. above, and where does he obtain these data?

e. How does he evaluate and synthesize his data inputs to arrive at his element-by-element cost estimates?

f. How does he structure his separate element costs into a total system cost and how does he present this estimate in the most meaningful and useful format to his client?

1.7 Summary

The purpose of this document is to delineate the major steps involved in costing a military system.

When properly used, a cost estimate can assist the military planner in selecting his systems so as to maximize the total effectiveness of his military forces.

Cost is important as one of the decision-making criteria to the military planner because total resources are in short supply; hence an overcommitment or an unwise commitment of resources in one program automatically reduces resources available to other programs without commensurate benefit and thereby weakens the total military strength of the nation.

It is important that military system costs be estimated reliably because, if cost is used as a decision criterion, a wrong cost estimate can lead to a wrong system decision with consequent reduced total military effectiveness and severe economic dislocations.

It is difficult to estimate the costs of a military system accurately because the accuracy of these estimates depend upon correctly determining the highly unpredictable system configuration, because these systems are becoming increasingly complex, because necessary data are sparse and of questionable quality, because difficult conceptual problems must often be resolved, and because the lack of a formalized methodology obliges the estimator to devise many of his procedures on an ad hoc basis.

Despite the obvious design and functional differences among systems, there are certain basic tasks involved in costing all systems. This document aims to identify these tasks and to provide some inkling as to how they may be performed.

FOOTNOTES

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[1] Primary credit for this new outlook on the role of the cost estimate is due principally to RAND Corporation economists: Charles E. Hitch (currently Assistant Secretary of Defense, Comptroller), Roland McKean, Alain C. Enthoven (currently Deputy Assistant Secretary of Defense, System Analysis), David Novick, etc. Secretary of Defense, Robert S. McNamara has, of course, reorganized the management of the entire national defense program around this concept. 4

[2] Charles J. Hitch and Roland N. McKean, The Economics of Defense in the Nuclear Age, (Harvard University Press, 1960), p. 3. 8

[3] G. H. Fisher, "A Discussion of Uncertainty in Cost Analysis (A Lecture for the AFSC Cost Analysis Course)," RAND RM-3071-PR, April 1962. 9

[4] M. G. Pritchard, "Reporting - Air Force Reporting and Contractor Needs," Air Force Systems Command Management Conference, May 1962 (Monterey, California), pp. 4-6. 10

[5] Testimony before the House Appropriation Committee, Part V (March 1964), p. 477. 12

[6] Cited in an address to the New York Society of Security Analysts, 7 August 1963. 13

[7] Specific data in this area are frequently classified for security reasons or are restricted from public release for proprietary reasons. However, some unclassified data are to be found in an otherwise classified Air Force report: USAF 61 WWZ-188, "System Acquisition - Cost and Control," pp. 10-23. Another brief, general, unclassified discussion of this subject may be found in C. E. Hurst, "Why Systems Engineering," Ordinance Magazine, September-October 1962, pp. 175-176. 13

[8] Alain C. Enthoven, "Choosing Strategies and Selecting Weapon Systems," United States Naval Institute Proceedings, January 1964, p. 154. 15

[9] Jay Forrester, Industrial Dynamics, (MIT Press and John Wiley and Sons, 1961), p. 2. 18

CHAPTER 2

ASCERTAINING THE PURPOSE OF THE ESTIMATE

2.1 A Kit Of Tools

The cost analyst's first responsibility is to ascertain as specifically as possible how his client intends to use the cost estimate he has requested. This is important because the purpose of the estimate can importantly influence the methods used to estimate a system's cost. In effect, this is to say that system cost methodology consists of a kit of tools, rather than a single standard set of procedures, and that this methodology must be varied selectively to fit the intended application.

Before examining the specific manner in which the intended application of a cost estimate can influence the methods used to derive the estimate, it is pertinent to discuss briefly in a general way the terms "client" and "applications".

2.2 Costing Applications

Relative to applications, cost estimates are desired for many purposes. There is, however, no exhaustive, mutually exclusive, well-defined, authoritative, centrally available cataloguing of the types of such applications. Some of the applications referenced in the literature are: programming, funding, budgeting, contracting, pricing, financial management, forecasting, comparative analysis, system design and analysis, etc. Among the uses of cost estimates on the above list and among the uses not identified above, there is considerable overlap. In this area, as in many other fields, different terms have similar meanings to different people.

However, from the point of view of methodology, there are basically two types of estimates, although in practice there are many variants of these two types. The first type of estimate is a planning type estimate and is intended as an input to a system analysis study. This type of estimate is intended as a tool to help the decision maker reach a cost/effectiveness choice among alternative systems for satisfying a specified requirement. The second type of estimate is a funding type estimate that aims to provide a basis for soliciting funds to implement a specific design or acquisition program.

2.3 Cost Clients

Relative to clients, many organizations and many echelons of authority within given organizations seek cost estimates. Usually the cost estimate is one segment of a broader system study or program proposal and, in effect, the cost analyst normally has several levels of clients for a given estimate. Since the study or proposal of which the cost estimate is an integral part usually must be approved by several or many echelons of authority before it is acted upon, the cost analyst actually has both immediate and ultimate clients for a given estimate.

Organizationally speaking, many agencies, public and private, are engaged in making and reviewing military system cost estimates. On the highest level of the government, the Bureau of the Budget, the Congress, and in some cases the President,himself,review Department of Defense programs and proposed expenditures and weigh the advantages of specific Defense Department programs vs other type programs as a means of promoting the national welfare. On a top military level the Department of Defense reviews and monitors the estimates prepared by the three Services. Within each Service higher echelons review and monitor the estimates generated at lower echelons. For instance, AFSC and Headquarters USAF approve the estimates submitted by each of the AFSC Divisions, e.g.,(ESD, ASD, BSD, & SSD) and prepared by various organizational units within these Divisions. Additionally, industrial contractor normally include cost estimates with the various system proposals, both solicited and unsolicited, that they submit to the military services. Finally, technical support organizations use cost estimates in their system analysis work in ascertaining the cost/effectiveness trade-offs of various system alternatives.

Since the way that a cost estimate is used can vary as it is transmitted through different channels, a problem confronting the cost analyst is how to formulate and present his findings so that they will be properly interpreted by his immediate, intermediate, and ultimate clients. Another problem is that the cost analyst does not always know for sure who his ultimate clients are or specifically how they will use his findings. Chapter 9, dealing with presentation and documentation, will offer some guidance on these matters. Additionally, the balance of this chapter will be devoted to explaining some of the methodological differences that apply when making estimates for the several different purposes.

2.4 Costing Concepts

Among the most important differences between a planning and funding type cost estimate is that they are based on importantly different concepts of cost. The funding type estimate measures the amount of money, the number of dollars, that will be required to implement a particular program or a system. It represents what methodologists call a "cash flow" concept.

On the other hand, planning type cost estimates are based on what methodologists call a "value flow" concept. Several writers also have described this concept as an "alternative use value cost". Thus, G. H. Fisher has stated that "... the cost of obtaining a certain objective at some point in time is measured by the resources that are not available for use in attaining alternative objectives becuase these resources are committed to the chosen objective."[1] Similarly, W. A. Niskanen, Jr. has stated that "the cost of a weapon system is the measure of the resources committed to that system at their relative value in other uses."[2] In practice what this frequently means is that a planning type estimate, in addition to relevant money costs, will also include cost generated by a program that are not directly or immediately reflected in money costs. For example, this concept of cost would include the "opportunity costs" of using a valuable, multi-use inherited asset in one employment rather than another. It would also take account of the "inputed cost" represented by a reduced effectiveness in an original system A that may result from the introduction of a new system B in which B shares with A the services of certain joint-use type assets. Chapter 8 will discuss in more detail the problems involved in handling such opportunity and inputed costs.

2.5 Scope Of Activities To Be Costed

One of the valuable contributions of RAND costing methodology has been the total activity concept. This concept states that all of a system's costs both direct and indirect from "the cradle to the grave", from initial concept to final termination, should be taken into consideration in preparing an estimate. Practically all system cost analysts now subscribe to this principle and the Department of Defense Programming procedures prescribe that the costs of all program elements (systems) are to include and itemize the RDT&E (Research, Development, Test, and Evaluation), Initial Investment, and Operations Costs covering a five-year period. Although this total activity principle in its general statement is quite valid, it is important to note how the purpose of the estimate may sometimes justify including something less than the "total" costs of a system in an estimate.

It was mentioned in 2.4 above that funding estimates are cash flow estimates and by definition exclude opportunity, inputed, and other non-cash costs. In this sense a funding estimate would be narrower in scope than a planning type estimate covering the same system alternative.

On the other hand, a planning type estimate may sometimes properly omit whole areas of cost that would have to be included in a funding estimate. Since the objective in a planning estimate is to select the preferred among several system alternatives, certain major and minor areas of cost may be identical for each of the alternatives. Since these cost areas have a neutral impact, they may for purposes of intra-systems analysis be omitted without violating the purpose of the estimate -- to make a choice among alternatives. Especially, when the problem is to optimize some detail design within the context of a particular subsystem, the analysis can profitably stress the elements for which the cost impact differs from alternative to alternative. However, it would be a serious mistake to use this partial intra-system, planning type estimate for funding purposes. It would also be a mistake to submit this partial, intra-system, planning type estimate to higher headquarters for a planning type, cost/effectiveness comparison with other system proposals submitted by other echelons.

Thus, partial-type, narrow scope funding estimates are likely to omit certain costs properly included in a planning type estimate whereas partial-type, narrow scope planning type estimates are likely to omit costs properly included in a funding estimate.

2.6 Precision Level

As a general principle, it is desirable to minimize error in any type estimate since such errors almost always necessitate some revisions in approved programs. However, the client's intended use of the cost estimate can influence how important it is to be precise in deriving the total cost estimate or in estimating particular cost elements.

Frequently, it has been stated that a cost estimate oriented to support a funding request requires greater precision than one oriented toward making an advanced planning choice among several system alternatives. The primary rationale for this statement is that the immediate consequences of an error, especially an underestimate, are much greater in the case of a funding estimate. A serious underestimate in a funding estimate can cause a relatively early crisis in the affected program and lead to a cancellation or serious retrenchment either in that program, or in other programs if funds are diverted from them to make up the shortage in the referenced program. As indicated in Chapter 1, this condition not only reacts unfavorably on the nation's immediate military posture, but also vitally affects the welfare of major industries, communities, and thousands of individual citizens.

Normally, an error of equal magnitude in an estimate calculated solely to facilitate a planning choice among several alternatives will have less serious repercussions. When the nature of the error is such that it affects each of the alternatives similarly, the error will not affect the relative preference ranking of the alternatives That is, if the decision at hand is to make a definite choice among several specified alternatives, an underestimate of, say, $10,000,000 in the RDT&E costs of each of the alternatives would not swing the choice from one alternative to another.

It might, of course, affect the preference ranking of these alternatives relative to other alternatives not subject to this error.

Moreover, the indirect consequences of an error in planning-type estimates are normally less serious than in funding-oriented estimates. Since planning-type estimates normally go through several stages of review and reconsideration before heavy commitments to purchase equipment and facilities are made, an initial decision favoring a system can be revoked with fewer reverberations throughout both the military and civilian economies. For instance, if later information reveals an equivalent underestimate of $10,000,000 in the cost of each of several planning-stage alternatives, still other less costly alternatives can be developed and considered, including the possibility to undertake <u>no</u> new system in that particular mission area.

Finally, in the case of funding type estimates administrative-legal-political constraints may dictate that the analyst seek greater precision in certain cost elements than in others. Congress authorizes funds to the military services by certain classifications and sometimes some types of funds will be in tighter supply than others. In such circumstances the consequences of a cost error (an underestimate) in a tight-money supply category can be more serious than it would in other cost elements of equal magnitude. One practical problem in taking account of this condition is that the cost analyst is often poorly informed relative to these differential funding constraints.

2.7 <u>Consistency</u>

2.7.1 <u>General</u>

The purpose of the estimate also influences the extent to which the cost analyst must be concerned with "consistency" in his methodology. Of course, considering consistency in a generic sense, i.e., "a uniformity of practice" and "a harmony of parts," both funding and planning estimates are concerned with consistency. Consistency in this basic sense can be taken to mean:

a. it is desirable to define the elements of a cost estimate in a discrete and mutually exclusive manner, i.e. it is normally not desirable to include maintenance labor under "personnel costs" for one subsystem and under "equipment maintenance" costs for another subsystem.

b. it is desirable in any kind of a cost estimate to be consistent in the estimating relationships used to calculate like items of costs, such as military manpower, from one subsystem to another.

c. it is desirable to be consistent in the sense of following prescribed regulations or established practice, such as the procedures and ground rules followed in costing intermediate support or logistics services, as one proceeds from one costing project to another.

d. it is normally desirable to be consistent or uniform in bookkeeping procedures, such as in rounding off decimal places, for the cost estimates of different elements within a given system estimate.

Consistency in all of these senses apply alike to both planning and funding type estimates.

However, planning estimates more so than funding estimates are concerned with inter-system consistency in the sense of freedom from bias. This arises from the fact that planning estimates are an input to a comparative study of different system alternatives for meeting a given performance requirement, and there are numerous subtle ways in which such comparisons can be prejudiced.

The important criterion in avoiding bias in comparative analysis is to strive for consistency of impact on total system cost rather than merely consistency of procedure. This distinction is important because consistency (uniformity) of procedure can sometimes lead to inconsistency in impact in the following ways.

2.7.2 Excluded Costs

It was mentioned in Section 2.5 that it is sometimes legitimate in planning type estimates to make comparative, partial cost estimates, to exclude certain identical neutral elements from all system alternatives being compared. However, to do so legitimately, it is necessary to determine that the excluded item(s) has (have) equal cost impact on all alternatives. For instance, it would not be legitimate to exclude all personnel costs from each of two system alternatives if one system were a manual system using many personnel and the other an automated system using few personnel.

2.7.3 Non-Monetary Costs

Similarity, in the treatment of indirect, non-monetary costs, it would not be legitimate to cost all inherited assets as free to all system alternatives if some alternatives would use few or no inherited assets and other alternatives would draw heavily on valuable, multi-use inherited assets.

2.7.4 Element Accuracy

It was stated in Section 2.6 that precision and accuracy are less important to a planning estimate than to a funding estimate. While true, this proposition must be qualified in terms of a consistency of impact criterion. This applies, for instance, to the accuracy of the cost estimating relationships used to calculate a cost element. If one system alternative involves very little overseas travel, and a second alternative involves considerable overseas travel, it would certainly not be immaterial whether we used a correct factor of $700 per man transported or an incorrect factor of $70 or $7,000 per man transported.

2.7.5 Procedural Consistency

Sometimes an analyst must resort to different methods for calculating a certain cost element in different system alternatives. This may sometimes occur in advanced planning studies when relatively incomplete information is available on the alternative performance and design characteristics. Or sometimes the analyst may be asked to review for consistency and general validity the cost estimates covering system alternatives prepared by several different organizations that employed different methods for calculating a given type of cost. Thus, (1) in one case computer programming costs may have been calculated as $X per instruction for the program being established, (2) in a second case as Y% of the data processing mission equipment costs, (3) in a third case as $Z per programmer employed per year. The consistency criterion would require that the analyst determine that differences or similarities in the final dollar estimates of computer programming costs in the three instances could be traced to differences in the actual resource requirements for computer programming and not to peculiarities of the different procedures used to estimate the cost in each instance.

2.8 Sophistication of Technique

The purpose for which the estimate is to be used and the attendant constraints that impinge on the analyst may also influence the relative sophistication in cost methodology that is appropriate. Two examples will be cited.

2.8.1 Manual vs. Automated Methods

The purpose and type of estimate required may influence the choice of manual vs. automated methods for processing the cost inputs, performing the mathematical computations, and printing out the results of the study. When the client requires a cost comparison of numerous alternatives, such as in a planning type, cost sensitivity study, certain types of computer oriented cost models (RAND, MITRE, Research Analysis Corporation) can greatly reduce the time required to make the estimate. This is most likely to be true when the cost results are to be reported in terms of a relatively detailed, standardized set of cost categories and elements.

On the other hand, when only a single configuration is to be costed -- as is normally the case with a funding estimate -- a manual costing may be faster. This is most likely to be true when the total costs of the single configuration are to be subdivided into a relatively small number of cost elements, and this cost structure differs substantially from the standardized cost structure reflected in the cost model.[3]

2.8.2 Handling Uncertainty

Another way in which the client's purpose can influence the relative sophistication of costing technique employed concerns the way uncertainty is handled. Many times the client desires the cost results expressed as a single-valued estimate. For instance, funding requests to Congress must be stated as a specific sum of money. In such cases uncertainty is either ignored or is handled simply, e.g., an allowance for contingencies may be included as one of the cost elements that comprise the total cost estimate.

On the other hand, when the client's purpose is to make a choice among several alternatives, he may wish to give more detailed consideration to the various degrees of uncertainty surrounding the estimated costs of each of the alternatives. The personal desires of the client and his intended use of the cost results will determine the recommended degree of sophistication in the technique used to calculate and express this uncertainty. If only a rough estimate of this uncertainty is needed, the analyst may state that his best estimate is that the system will cost $50,000,000 and that he believes there is only one chance in ten that the system will cost less than $35,000,000 or more than $75,000,000.

However, if the client desires fuller, much, more accurate knowledge relative to uncertainty, the analyst may resort to relatively sophisticated, computer oriented, statistical methods to convert the uncertainty for each separate cost element into an explicit measure of uncertainty in the total cost estimate. The output of this calculation might take the form of a complete probability distribution of estimated costs.[4]

2.9 Summary

Even though similar tasks confront the analyst whatever the type of system he is costing, his approach to these tasks should vary with the purpose of the estimate.

Although there are many specific applications of cost estimates, methodologically speaking, there are two basic types. The first type, a planning estimate, is intended as an input to a system analysis study and is intended as a tool to help the decision maker make a cost/effectiveness choice among system alternatives for satisfying a specified requirement. The second type, a funding estimate, aims to provide a basis for soliciting funds to implement a specific design or acquisition program.

The methodology for accomplishing these two basic types of estimates differs in the following ways:

a. The most important difference is in the concept of cost employed. A funding type estimate employs a "cash flow" concept and aims to measure the number of dollars required to implement a program or system. A planning type estimate uses a "value flow" concept that costs the resources of a system at their "alternative use" value, i.e. the estimated value of a system's resources if they were used in other systems.

b. The scope of costs covered is another important difference. Although either a planning or funding type estimate may, under certain circumstances, legitimately include only partial, rather than total, system costs, the excluded costs in the two cases are unlikely to be the same.

c. Although it is desirable to minimize error in any type estimate, the requirements for accuracy are normally greater in a funding type estimate because an error in a funding estimate is likely to require greater readjustments in other military programs and the civilian economy.

d. Consistency is also a desirable characteristic in all estimates; however, it is harder to achieve consistency in planning type estimates. It is important to realize that a uniformity or consistency in procedure does not, per se, insure consistency in the impact on total system costs which is the important consistency criterion.

e. The purpose of the estimate also influences the relative sophistication of technique that is appropriate. For instance, planning type estimates normally can use to greater advantage complicated procedures for converting cost inputs into outputs via computer automated cost models and more sophisticated techniques for assessing and communicating uncertainty relative to the cost estimate.

FOOTNOTES

		Page
1	G. H. Fisher, "What Is Resource Analysis," an address at RAND Seminar, January 1963, p. 1.	27
2	W. A. Niskanen, "The Role Of Costs In Military Decision Making," an address to the Joint Conference of the Canadian Operations Research Society and the Operations Research Society of America, Montreal, 28 May 1964.	27
3	The possibility of saving time is only one of the advantages offered by a computerized cost model. The advantages and limitations of computerized cost models will be discussed more extensively in Chapter 7.	34
4	S. Sobel, "A Computerized Technique To Express Uncertainty In Advanced System Cost Estimates," The MITRE Corporation, TM-3728, (September 1963).	35

CHAPTER 3

DESCRIBING THE SYSTEM

3.1 The Historical Record

A second critical task in costing a military system is that the analyst must pin-point, as clearly as he can, what it is that he is to cost. This statement is such a common sense truism, and it has been repeated so often, that it represents almost a platitude to restate it here. And yet, it is precisely in this area of defining what might be called the non-financial inputs to a cost estimate that cost analysts have historically made their gravest errors. Although similar studies have been made by several organizations, a series of studies over a number of years by RAND economists have repeatedly shown that erroneous non-financial inputs have dwarfed in importance errors due to faulty cost estimating relationships and procedures.[1]

Perhaps it would be more precise to say that most serious errors in advanced system cost estimates in the past have been due to the fact that the system configuration changed substantially from the time the cost estimate was initially prepared to the time the system became operational, and not because the cost analyst wrongly priced the resources that constituted the initial design of the system. Clearly, if there is any single aspect of costing a military system that presents a major potential pay-off task, it is in new and better ways to define what is to be costed.

Before considering how this might be done, it might be relevant to speculate whether some of the grosser errors in anticipating a system's configuration might be due less to technological miscalculations than they are to semantic considerations. Perhaps it would sometimes be more realistic to change the system designation nomenclature attached to major changes in a program than to regard what is essentially a new program merely as a realignment or modification of an earlier, "primitive" concept.

Conceivably a cost methodologist could conclude from the RAND historical findings described above that the error-in-system-cost-estimates is not his problem; rather that it is the job of those responsible for setting the system requirement and for translating this requirement into a design to do a better job than they have in the past. For two reasons this outlook would not be very helpful. If the cost analyst is to produce more accurate cost estimates, he must be concerned with exogenous as well as endogenous factors bearing on his estimate. Second and more important, in many cases the cost analyst is a member of a system analysis team and shares responsibility for working up the configuration or design of a system, and, as will be discussed in Chapter 10, in some cases presently and in more cases potentially he can even influence the client's objectives. Hence, it is quite within the cost methodologist realm of responsibility to inquire what can be done to more accurately foresee in the early stages of a system's development the nature of its design in the later stages.

3.2 Sources of Error

There are at least four basic sources of potential error in the non-cost inputs to a cost estimate.

3.2.1 The Threat Analysis

An error in the assessment of the enemy threat is the first step in a complicated chain that can ultimately lead to an erroneous advanced system cost estimate. Thus, it might be assumed that air-breathing aircraft constitute the only threat that the United States faces from Country A in a designated time period. Subsequent analysis may determine that the United States faces both an aircraft and missile threat from Country A in the period indicated.

3.2.2 The General Mission Requirement

Assuming a certain threat, a miscalculation in the nature of the U. S. military capability needed to cope with this threat can also ultimately lead to a cost estimating error. Thus, it may initially have been assumed that to carry out a designated offensive mission it would suffice to have X% of United States aircraft continually airborne. Subsequent analysis may disclose that 2X% is a better figure.

3.2.3 Specific Performance Capabilities

Third, even if the threat and the general mission requirement have both been correctly assessed, a cost estimating error can arise from a miscalculation in the specific performance requirement needed to fulfill the mission requirement. For instance, it may have been estimated initially that to fulfill a designated defense mission, a 15-minute warning time would suffice. Later study may, however, reveal that to carry out this mission, a 20-minute warning time is required. Or it may have been initially calculated that a command post hardened to 200 p.s.i. would provide adequate protection against a designated type of enemy threat. Later study may, however, increase this figure to 400 p.s.i.

3.2.4 Design-Resource Translation

Fourth, even when the threat, the general mission requirement, and each of the specific performance capabilities needed to fulfill this requirement have been correctly estimated, errors may be made in determining the design implication of achieving these capabilities. In other words, it is easy to err in determining the types and quantities of resources that will be needed to achieve a designated performance level. Sometimes this is described as configuration uncertainty where "configuration" refers not only to the physical design of the system, but also to a description of how, where, and under what conditions the system will be used, i.e., the employment and deployment plans.

Illustrative of the types of configuration error that may develop are the following:

a. It may initially have been estimated that a single unit of a state-of-the-art computer could perform the data processing necessary to provide a 15-minute warning time. Later study may, however, reveal that it requires three units of a beyond-the-state-of-the-art computer - each involving added RDT&E, Investment and Operating costs - to provide the 15-minute warning time.

b. It may initially have been estimated that 100 military personnel after three months training at a average cost of $3,000 per man would be needed to adequately staff a designated installation. Later study may disclose, however, that it requires 200 personnel, after six months training at an average cost of $6,000 per man, to staff such installation.

c. It is not uncommon for an advanced design to completely overlook certain important resources needed to attain a designated performance capability. For instance, in a communication system it might be overlooked that some military bases would be far enough apart to require the system to have repeater stations.

3.2.5 Cost Estimating Error

In contrast to the foregoing three sources of error in non-financial inputs to a cost estimate would be an error in a financial input. For instance, in illustration b. cited above, it would constitute a cost estimating error if a later estimate had revised the cost of a three-month training program from $3,000 to $4,000 per man.

3.3 Understanding The System Acquisition Process

3.3.1 A Generalist's Knowledge

There is no quick and easy path to learning how to forecast in the early stages of a system project what the final configuration of the system will be. There are, however, both immediate and long-term steps that a cost analyst can take to improve his ability to define the system he is to cost.

The wisdom, long run, for the cost analyst to improve his knowledge of the total system acquisition process, is indisputable. Just as business firms have found that a top executive's ability to detect, diagnose, and solve practical business problems depends importantly on his appreciation and understanding of the broad economic and institutional environment in which the firm operates, similarly a cost analyst's ability to define accurately the system he is to cost is likely to be enhanced by a thorough knowledge of the administrative-technical mechanics of the system acquisition process. If the cost analyst has acquired a good understanding both conceptually and historically as to what goes on as a system moves from a concept to an operating reality, he should be able to identify more readily the specific areas in his own study in which early conceptions are likely to change, and what are likely to be the resource implications of these changes.

3.3.2 The Institutional Process

A thorough knowledge of the institutional process through which major military systems are conceived, developed, and introduced is a first requirement. For instance, the cost analyst should be familiar with the mechanics of the Department of Defense programming system and the system management regulations of the individual military services such as the Air Force "375" series. These regulations are supplemented by a growing unofficial literature that provides a valuable conceptual background on this total process.[2]

3.3.3 System Design Methodology

Many methodological (normative) studies dealing with the system design process have also been published. These studies generally seek to crystalize the essential tasks in developing any system, and to point the way toward an objective approach for accomplishing these tasks.[3]

3.3.4 Historical Studies

To supplement an institutional and conceptual background relative to the system acquisition process, an analyst should familiarize himself with the historical details as to how representative major military systems have developed. Various official and private studies have reported and interpreted the histories of certain major systems.[4] Additionally, of course, if the analyst can gain access to the unpublished "system" files of either the military services or individual contractors he will find much useful information to explain how and why specific systems' objectives and configurations have changed as they have evolved from concept to operation.

In this connection the Program Change Proposal System of the Department of Defense should in time provide valuable historical insight into what happens to change the objectives and configurations of major military systems. Through this PCP system the Department of Defense has sought to systematize the procedures and documentation, including rationale, associated with making changes to officially approved military programs. Access to these files is, of course, officially controlled, but perhaps eventually DOD will undertake to consolidate, evaluate, and publish the results of its experiences with the PCP a la Peck and Scherer.

3.3.5 Technological Innovation

The development of a modern military or space system represents one of the most complex practical applications of systematized, scientific innovation that can be found. In recent years a number of interdisciplinary studies have sought to probe the general historical and conceptual facets of the innovation process. Selected portions of this work are also relevant to cost analyses, and to system analysts in general, who are interested in becoming more adept in foreseeing the eventual configuration of systems while they are still in the conceptual stage.[5]

3.4 Operating Principles

While he is acquiring a well-rounded background on the total system acquisition process that will do more than anything else to improve his long-run cost estimating abilities, the cost analyst can improve almost immediately his ability to define more accurately the system he is to cost. He can do so by following certain basic principles.

3.4.1 Clarifying the Cost Analyst's Responsibilities

All cost analysts do not have the same backgrounds, and the constraints of the study, including the client's wishes relative to the cost analyst's responsibilities, are not always the same. Ideally, the cost analyst should have sufficient background in engineering and related disciplines so that he is capable of participating as a member of the system design team. In practice, this may not be the case. Even if he has the necessary background, the administrative ground-rules of the study may preclude him from being a member of the design team.

Even when he is not a member of the system design team, it is important that the cost analyst, his client, and his associates having other disciplinary backgrounds, recognize that the mechanics of making a cost estimate properly go beyond a purely cost-accounting pricing of resources. Although it would certainly be improper and intolerable for the cost analyst to rely on his judgment for engineering-scientific type inputs, it is equally certain that the cost analyst should be persistent in pressing his client and associates relative to the validity of these inputs and the specific characteristics of the system he is to cost.

3 4 2 Pinpointing the System [illegible]gation

Operationally this means that the cost analyst, if he is not a member of the design team, should engage in a type of "20 questions" procedure. At the onset of a study he is usually apt to suffer from serious uncertainty surrounding the general statement of the requirement and also from the fact that the requirement has not been translated into the performance specifications and the design configuration necessary to meet it. It is incumbent on the cost analyst not only to press his client for greater and greater clarification of the general statement of the requirement, but, equally important, to insist that this requirement be translated into the performance specifications and design configuration - including an identification of the types and quantities of assets and services needed to meet the requirement.[6] If he is a member of the system design team, he is, of course, in a better position to see that these conditions are met.

The importance and value of this translation can hardly be overestimated. The responsibility of the cost analyst is to determine the resource costs of attaining a future capability; however, a performance requirement, itself, does not directly generate a resource cost. It is strictly through the medium of a design or configuration that the performance requirement can be translated into a meaningful statement of resource needs. This is true because almost always there are numerous, sometimes almost innumerable, design alternatives for achieving a designated performance requirement, and each of these design alternatives has its own differing resource implications. Any statement or equation which depicts a specific relationship between performance and costs must either explicity postulate certain design assumptions or implicitly assume them.

Of course, both the time constraints and the nebulous nature of the system that he is trying to cost, will frequently oblige the cost analyst to settle for a less precise definition and translation of the requirement than he would like. This is likely to be especially true when the requirement he is costing implies an advance in the technological state-of-the-art. However, it is important that both the analyst and his client be fully aware that in settling for a nebulous and incomplete statement and resource translation of the requirement that they are, perforce, increasing the range of uncertainty and the likelihood that the estimate may be seriously wrong.

3.4.3 Configuring Technological Improvements

A third principle is an outgrowth of the second and is directed toward defining and costing system elements involving technological advances beyond the current state-of-the-art. Frequently, serious errors are committed in defining and costing such developments largely because the approach to their definition and costing is so largely intuitive.

Admittedly, it will never be possible to make the process of defining and costing new developments as explicit as is the process of costing elements entirely within the state-of-the-art. However, the process of defining and costing new developments can be made much more systematic and the area of uncertainty surrounding such developments can be both greatly reduced, and made more explicit, if it is realized that no new requirement, however novel, represents a complete departure from everything that has gone before. Innovation generally consists of small increments of improvement, and usually represents new combinations of established capabilities. One leading authority has suggested a rough rule of thumb that the typical new capability in the area of component requirements consists of "20 per cent new, 80 per cent old "[7] It should be a major objective of the cost analyst, with the help of his client, to identify those design and resource implications of a new performance capability that represent carryovers from the existing state-of-the-art.

Planning factors and cost estimating relationships in the available data base are critically important in identifying these carryovers and in translati performance requirement into a design configuration, and a design configuration into a resource estimate covering the types and quantities of assets and services necessary to achieve the performance requirement. In the first instance, performance characteristics are the independent variables and design characteristics the dependent variables, and subsequently, design characteristics are the independent variables and resource requirements the dependent variables Some of the essential conditions of this process have been discussed in previous MITRE documents[8], and additional observations pertinent to the operational characteristics of this process will be discussed in Chapters 5 and 6

3.4.4 <u>Reiterating the System Description</u>

A fourth important principle to be observed in defining the system to be costed is that in an advanced planning study this definition must be a continuing job, not a one-shot task to be completed at the beginning of the study. This necessity for reiteration in definition stems from the fact that at the onset of the study the client and the designers usually have only a vague and fluid notion relative to the details of the performance goals and of the design details necessary to meet these goals. In a very real sense the cost analyst who participates in an advanced planning study is shooting at a moving target He cannot operate effectively in isolation from the other members of the study team; it is crucial that he establish close working relationships with the engineering and scientific staff primarily responsible for the design of the sytem. If the final cost estimate is to be a useful input to the decision maker it must reflect the resource implications of the latest requirements and design.

3.4.5 Quick Response and Flexibility

A fifth principle follows from the fourth and stresses the need for flexibility and rapid response in estimating procedure. As will be pointed out in Chapter 5, the limited time available for accomplishing the cost estimate is almost always a constraint, and the analyst should be able to change quickly the quantitative and qualitative characteristics of the system he is costing.

Herein potentially lies both an advantage and a shortcoming of certain computerized cost models which mechanize the process of converting cost inputs into outputs, i.e., into the total system cost estimate. When a project requires a fairly detailed shred-out of costs into many interdependent elements, a single change in a major element - such as mission equipment - can ramify throughout the entire structure. If these changes must be reflected through many alternative configurations, the sheer calculation involved can be prodigious. Under such circumstances, a computerized estimating procedure can be a great time-saver.

On the other hand, if it becomes necessary to reflect qualitative changes in the computer model - such as a change in the elements structure or in the definition of the elements - it may be relatively time consuming to do so. Normally, it is desirable to avoid such changes once a cost study is fully underway, whether or not a computerized model is being used to process the cost inputs, make the necessary calculations, and print the resu. However, such contingencies do sometimes occur, and it is well for the cost analyst to keep the need for flexibility in his procedures in mind.

3.5 Summary

The message of this section has been comparatively simple. Historically, by far the most important reason for poor cost estimates is that the system configuration changed substantially from the time the cost estimate was made to the time the system became operational. If future estimates are to be better, the cost analyst and those from whom he receives his descriptions of the non-cost characteristics of the system must do a more accurate job of defining and translating the requirement to be costed. The cost analyst must accordingly make these definitions and translations early and continuing items on his procedural agenda. If he fails to secure them, he does so at great peril, and in so doing, subjects his final cost estimate to the possibility of serious miscalculation

Although the objective sought can be stated simply, there is neither a quick nor an easy way of anticipating in the early stages of an advanced system study the eventual configuration of the operating system.

However, the cost analyst can do much to improve his long-run ability to define more accurately the system he is to cost, if he strives to learn as much as possible about the system acquisition process; i.e., what happens as a major military system proceeds from concept to operation. This knowledge should be both descriptive and normative and should cover the historical, legal, administrative-political, conceptual, and technological aspects of developing a system. An analyst so fortified with an intimate knowledge of the system acquisition process in each of the referenced areas, will most certainly be better able to identify the attributes of the system on which he is working that are most likely to change and thus be better able to anticipate in the early stages of a system what the eventual configuration is likely to be.

While he is acquiring this long-run background, there are certain principles that he can observe in the short run to minimize the chances that he will commit some of the past errors of many cost estimators.

a. First he should strive for a broad, rather than a narrow, responsibility on the system analysis team. This means that he should take some responsibility for the definition of the system he is to cost. In practice he should be constructively critical of the non-cost inputs relative to the performance requirements and system configuration that he receives from his client, his associates, or that he provides himself.

b. Second, to the maximum extent that time and data permit, he should seek a translation of the general requirement into a set of performance specifications, and a translation of these specifications into a design configuration to include an identification of the types and quantities of resources to achieve these goals.

c. It will help him immensely in defining and costing a development beyond the state-of-the-art if he recognizes and proceeds on the assumption that any new development generally consists of new combinations of things that have been done before. His key job in defining a new development thus should be aimed at identifying these carryovers in subsystems, components, and activities for which he can find performance, design, and cost-estimating/relationships in the general data base.

d. In an advanced system study it is particularly important to recognize that the task of defining the system is a continuing one, not a one-shot undertaking to be completed at the beginning of a study

e. Because of the evolving character of the system, cost estimating procedures and formats should be flexible in the sense that new inputs, financial and non-financial, can be admitted without complication or serious loss of time.

FOOTNOTES

	Page
[1] A good summary of this work is contained in G. H. Fisher, *op. cit.*	38
[2] E.g., J. F. Jacobs "Design Approach for Command and Control" MITRE SR-102 (January 1964) Another example is the ESD-SDC MITRE sponsored "Electronic Systems Acquisition Process". (MITRE TM-69, October 31, 1963).	43
[3] Pertinent in this regard is the work of the Society for General Systems Research. Illustrative of the numerous published literature in this field are:	43

K. S. Schaeffer, The Logic of An Approach to the Analysis of Complex Systems (Stanford Research Institute Project No. IMU-3546), 1962

A. D. Hall, A Methodology for Systems Engineering, D. Van Nostrand Co., Princeton, N. J. (1962).

H. H. Goode and R. E. Machol, Systems Engineering McGraw-Hill Co., New York, N. Y. (1957).

Donald Eckman (ed.), Systems. Research and Design John Wiley & Sons, N.Y., (1961).

D. O. Ellis and F. J. Ludwig Systems Philosophy, Prentice-Hall, Englewood Cliffs, N. J. (1962).

[4] E.g., M. J. Peck and F. M. Scherer The Weapons Systems Acquisition Process. An Economic Analysis (Harvard University Press, 1962); also USAF 61 WWZ-188, Systems Acquisition - Cost and Control.	44
[5] Illustrative of this work is a study edited by the National Bureau of Economic Research entitled The Rate and Direction of Inventive Activity, 1962, Princeton University Press (see, for instance, a paper in this study by Richard R. Nelson. "The Link Between Science and Invention: The Case of the Transistor"). Another interesting study is. Lauren B. Doyle, "How to Plot a Breakthrough" System Development Corporation, SP-1492.	44
[6] The step-by-step procedure involved in pinpointing a system description and in identifying the resource implications of such a description is illustrated in. J. P. Large (ed.) Concepts and Procedures of Cost Analysis, RAND RM-3589-PR June 1963 (Chapters VII-XII).	46
[7] David Novick, Costing Tomorrow's Weapon Systems, RAND RM-3170-PR (1962).	48
[8] M. V. Jones, Cost Factors as a Tool in Military Systems Analysis, MITRE TM-3172 and E. I. Friedland, On the Construction of Cost Estimating Relationships, MITRE WP 5440. E. I. Friedland and J. R. Miller, A Search for Computer Cost Estimating Relationships, MITRE WP 6595, E. I. Friedland and J. R. Miller Computer Cost Estimating Relationships User's Manual, MITRE WP 6596	48

CHAPTER 4

SELECTING COST CLASSIFICATIONS

4.1 The Cost Structure

Webster lists nine or ten definitions of the word "structure". Some of these are specialized to particular fields of science such as geology, chemistry, psychology, etc. However as used in this document, the term structure is employed in a rather generic sense as "an arrangement of parts that furnishes some insight relative to the functional inter-relationships among these parts" Thus, a cost structure is an arrangement, a classification or a subdivision of the constituent types of costs in a total cost estimate that furnishes some insight concerning the relationships of these costs to each other and to the total system cost.

4 2 The Importance Of Proper Classification

It is important to discuss the subject of cost classification in a methodological treatise, such as this, for at least three reasons:

a In most actual costing projects considerable time is spent and often controversy generated relative to the preferred classification scheme.

b A substantial portion of the total literature labeled system cost methodology is concerned with cost classification schemes and with principles relevant to making such classifications.

c. The way that costs are classified can either help or hinder the analysis and decision-making processes. Whereas one classification scheme will shed light on important cause-effect relationships, another will obscure those relationships.

4.3 Cost Formats

A total system cost estimate can be structured in many different ways. However, for the purposes of this document it is useful to distinguish between two basic types of cost structures. One is an input format that is intended to facilitate the collection of relevant data to make the estimate. A second type is an output format that is intended to facilitate the presentation of the findings of the cost study.

With a few notable exceptions, comparatively little time has gone into developing input formats. Most attention has been paid to specifying desired output formats (reports), with the question of the format under which the data will be collected left to the discretion of the reporting office.

In some cases an analyst may, depending upon the type of data available, use the same format to collect his data and to report his findings.

In other cases, the input format may be drafted in consonance with the classification scheme of a formal departmental data bank and as a part of a sophisticated cost model. MITRE has such a program; the objective of a cost input format developed in connection with its electronic system cost model is to provide a relatively detailed, carefully cross-classified scheme whereby it is possible to derive several different output formats from this one input format.

4.4 Criteria For Classifying Costs

The selection of a cost structure, particularly an output format, frequently results in a highlighting of one type of cost as opposed to some other. Thus, if one type of cost is shown on a first-level, major element status, another element may have to be shown on a lower level, sub-element basis in which it may lose its individual identity. Although sometimes no set of criteria can resolve definitively which is the preferred of several classification schemes, on other occasions a number of criteria can be invoked to indicate a preferred choice. Illustrative of these criteria are the following.

4.4.1 <u>Relative Magnitude</u>

A classification structure should normally highlight the quantitatively largest elements and relegate the smaller elements to lesser status. This criterion is based on the premise that cost categorization should help the analyst and his client to learn as much as possible about the detailed make-up and behavior of the individual costs that are most relevant to determining the magnitude of total costs. Expressed differently, categorization should be a culling device that differentiates the significant from the insignificant. Accordingly, two or more large cost items should not lose their separate identities by being consolidated under a single element, and very small cost items should not be reported on an equal element status with very large items.

The following example illustrates this criterion:

Categorization I		Categorization II	
Cost Item	% of Total Cost	Cost Item	% of Total Cost
A	20	A	20
B	70	B_1	25
C	5	B_2	30
D	3	B_3	15
E	2	C, D, E	10
	100		100

In this example, Categorization II by separately identifying the three largest components of cost item B would generally be more useful both for analytical and presentation purposes than would Categorization I that buried these three large cost components under one element and reported as separate elements the smaller items, C, D, and E.

4.4.2 Purpose of the Estimate

The specific purpose of the estimate and the client's intended application of the estimate as discussed in Chapter 2 can sometimes importantly influence the preferred classification of costs. For instance, it may be important in an estimate oriented toward funding purposes to identify separately certain relatively small cost elements because in a total force context such funds are in short supply or are politically sensitive. Also, in the case of design-oriented estimates covering alternative configurations in a cost-effectiveness study, it becomes important to show the separate cost impacts of the most cost-sensitive elements regardless of the average quantitative impact of these elements.

4.4.3 Type of System

The type of system being costed obviously influences the nature of the classification scheme. The cost structure covering a detection and warning system generally is likely to be organized around the sensor equipment that comprises the major item of such a system. On the other hand, the cost structure covering a headquarters command system may make no provision for sensor-equipment-related costs since the system typically has no sensor equipment. For similar reasons the cost structure pertaining to a weapons systems will normally differ in important particulars from that of electronic systems, especially at the minor element level.

Finally, although there are sound reasons for normally separating development (RDT&E) from investment costs, some systems require practically no development costs and when this is true there may be little to gain from separating the two types of costs.

4.4.4 Availability of Data

In establishing a set of cost categories and elements to be used in costing a system, it must be considered whether data can be collected to complete the preferred categorizations. This means that a check must be made relative to the formats and reporting regulations under which the military services and the Department of Defense collect their data and the back-up accounting records maintained by industry. As a practical matter it may frequently be necessary to compromise on using a theoretically preferred set of categories and elements simply because the government and industry do not compile and classify basic cost data in a manner such that it would be readily possible to segregate costs into these categories and elements. For instance, on occasions it would be interesting for planning purposes to estimate separately the operating and maintenance portions of military personnel costs. However, official data sometimes do not make this distinction. Also, at times it would be interesting to know the separate costs for material and labor charged under industry equipment maintenance contracts. Again, these data are not always available.

4.4.5 Discreteness in Definition

Apart from the particular purpose of an estimate or the type of system being costed, it is desirable that cost categories and elements be defined so as to be discrete and mutually exclusive. Both conceptually and administratively a cost structure should differentiate clearly between one type of cost and another, ideally there should be no question regarding the specific category or element under which a type of cost has been recorded or is to be recorded. Conceptually, it is sometimes difficult to avoid overlap and to draw these boundary lines clearly. Even in these cases, however, it is important that precise, albeit somewhat arbitrary, definition be used to avoid any misunderstanding between the cost analyst and his client as to how the marginal cases have been handled.

4.4.6 Completeness in Coverage

Before finally selecting a classification scheme, a check should be made to insure that all relevant types of costs have been provided for. This means that provision should normally be made to include the life-cycle, total activity costs of a system unless the special purpose of an estimate dictates otherwise. Chapter 3 discussed some of the conditions under which a partial cost estimate would be relevant. As indicated previously, it is very important to justify such partial analysis.

4.5 Advantages of Standardized Cost Structures

To take a vantage of the numerous advantages discussed below, practically all organizations that have established a formal system cost-estimating capability have developed standardized cost structures that can be used from system to system and from one costing project to the next. Some of these advantages are general in character and are long run in impact; others have short-run, immediate benefits for particular costing projects.

4.5.1 Conceptual Superiority

Standardized cost structures normally are more likely to meet most of the criteria discussed in Section 4.4 of this chapter than are the cost structures developed in the course of an individual costing project. This is true because generally much greater care and thought go into the development of standardized cost structures than into the cost structures developed to satisfy purely the requirements of particular costing projects. As will be discussed in Chapter 5, the cost analyst working on a particular costing project is usually faced with a serious time constraint and he is not normally in a position to be meticulous in defining each cost element and in ensuring that the total structure is complete and internally consistent. On the other hand, generalized or standardized cost structures are usually developed as methodological projects and specific provision is made for the thoroughness in procedure sometimes lacking in individual projects.

Similarly, a generalized cost structure developed in detached isolation from the peculiar biases of any particular project is more likely to take into consideration broad, basic, long-run concepts and and principles that are relevant to all systems and system projects. A cost structure tailored solely to fit the immediate, peculiar needs of one project is likely to sacrifice conceptual neatness for practical expediency. The consequences of this sacrifice are enumerated in the sub-sections that follow.

4.5.2 Time Conserving

The availability of a standardized cost structure conserves time of the analyst on any costing project because it greatly reduces the amount of time that he must spend in such cost preliminaries, as defining his cost elements. Such availability thus makes it possible for the analyst to spend his limited time on the very important functions of collecting and evaluating data.

4.5.3 Completeness Check-List

Following from several of the advantages cited above (particularly 4.5.1), a standardized cost structure, since it aims to be thorough and exhaustive, serves as a valuable check-list to ensure that no important cost elements have been overlooked in developing a specialized cost structure for a given project.

4.5.4 Intersystem Comparison

The use of standardized cost structures facilitates a comparison of the cost findings of different studies completed by different analysts over time since the standardized element definitions insure a consistent handling of difficult and controversial conceptual issues relative to such definition.

4.5.5 Using History

Standardized cost structures help the analyst extract the maximum possible benefit from historical data on the cost experiences of previous systems. This is important because the ability to forecast future costs accurately is related rather directly to the volume of usable historical experience that can be applied to such forecasts. To take one example, without a substantial comparability of cost element definitions from system to system and from project to project, it would be extremely difficult to develop reliable cost-estimating relationships (see Chapter 6), an indispensible tool in forecasting future costs. For instance, if equipment maintenance costs were defined differently in every costing study, historical comparisons of maintenance costs for similar equipment from system to system would be of very limited value.

4.5.6 Analyst-Client Communication

A standardized cost structure facilitates communication and minimizes misunderstandings between a cost analyst and his client, especially when there is the requirement for repeated contacts on successive projects between the cost analyst and a given client.

4.5.7 A Methodological Base

A standardized cost structure contributes to a generally improved, objective, methodological base. In system costing, as in any field of learning, it would be impossible to go far toward developing sophisticated techniques for handling difficult areas of cost (see Chapter 8) until there had been fairly general agreement on terminology. An important segment of this terminology consists of the definitions and the classification interrelationships among the types of activities and resources that are to be costed.

4.6 Cost Structures in Current Use

As indicated in Section 4.5, most agencies and organizations engaged in costing military systems have endeavored to introduce some degree of standardization into their cost structures. The extent of this standardization has varied considerably among organizations and applications. Also, as indicated previously, more attention has been paid to standardizing system cost output formats (reporting or presentation formats) than to standardizing input formats, the classification schemes used to collect the data necessary to complete the output formats.

4.6.1 Output Formats

There are both official and unofficial system cost estimating output formats. The official formats consist primarily of reports required from military contractors by military agencies plus those required by higher echelon military agencies from lower echelon agencies.

One of the most frequently prescribed bases for presenting official system cost estimates is by Congressional Appropriation Codes, the categories into which Congress subdivides and distributes the total military budget.

The Air Force portion of the Appropriation Codes contain sixteen (16) codes or elements. Seven (7) of these are major elements, dollarwise, from a systems' point of view:

Aircraft Procurement

Missile Procurement

Other Procurement (including Electronics)

Military Construction

Operations and Maintenance

Military Personnel

Research, Development, Test, and Evaluation

The other nine (9) codes cover such activities as Reserve Forces, the Air National Guard, Retired Pay, etc.

Another widely used summary classification is by the three major activities: Research, Development, Test, and Evaluation; Investment; and Operations.

Some of the reports classified on either or both of these bases are:

a. The Department of Defense's Force and Financial Plan, is a report which lists the several hundred DOD officially approved programs for the three Military Services. This report subdivides the costs of the major military programs both by the appropriation codes and by the three major categories - development, investment, and operations.

b. The DOD Program Change Report, the report used by the Three Services to request changes in DOD officially approved programs, also subdivides the costs of the revised programs into the development, investment, and operations categories

c. The System Acquisition Program reports, used by the AFSC Division (ESD, ASD, BSD, and SSD) to propose new programs to AFSC and Higher Headquarters, also subdivides system costs into the appropriation codes identified above plus the development, investment, and operations codes. The Proposed System Package Program, the document that covers the Definition Phase of the Acquisition Program, provides for a finer subdivision of costs under the appropriation codes. The format of this finer subdvision is within the discretion of the office preparing the report.

Air Force financial reports from the lower echelons to high echelons have also subdivided the Appropriation Codes data into two further levels. First, there has been a breakdown of the Appropriation Codes into numerous Budget Program Activity Codes (BPAC), plus a four-level breakdown of the BPAC Codes into many detailed Material Procurement Codes covering Investment (mainly hardware) type costs. For Command and Control Systems the first or major level breakdown of the Material Program Codes has included a system integration or system engineering element plus five mission equipment codes -- radar and sensors, electronic data processing equipment, communication equipment, data display equipment, and other mission equipment.

Two major reporting systems by which contractor costs are reported to the Air Force are the Contractor Cost Studies and the PERT (Program Evaluation Review Technique). The formats for these reports presently are not standardized.

As this is being written, the Department of Defense has issued a new directive that seeks to standardize reporting to DOD by the three Services.[1] The electronic system portion of this report has not yet been published. However, the aircraft and missile portion provides for a three-level breakdown. "Level Zero" provides for a classification of costs by major weapon system. "Level One" provides for a mandatory seven (7) element subdivision for each major system as follows:

Vehicles or Mission Equipment

Support Equipment

Systems Engineering

Systems Tests

Training

Site Activation

Other (primary Documentation)

"Level Two" provides for a 28 element subdivision, nine (9) of which are mandatory. Six (6) of the mandatory codes cover mission equipment codes; the other three (3) cover system integration, military construction, and documentation.

Most non-government organizations, such as RAND and MITRE, engaged in costing military systems also have developed standardized cost output formats.

Thus, the major or summary format utilized in most MITRE system costing studies during the last three years has been as follows:

<u>Research, Development, Test and Evaluation</u>

System Design and Management

Subsystem Development and Testing

System Integration, Testing and Evaluation

<u>Initial Investment</u>

Facilities

Mission Equipment* and AGE (Aerospace Ground Equipment)

Initial Spares and Stocks

Computer Program Production

Personnel - Initial Training and Travel

<u>Annual Operations</u>

Facilities Maintenance

Equipment Replacement and Maintenance

Communications and Equipment Rental

Computer Program Maintenance

Personnel

The above format is also utilized as one of the cost presentation formats in connection with MITRE's Electronic System Cost Model. The MITRE Cost Model also provides a more detailed subdivision of the above format plus a classification of costs by appropriation codes of the summary format, the various subsystems and the major hardware subsystems.[2]

4.6.2 <u>Input Formats</u>

In collecting cost data inputs the analyst sometimes uses an integrated format that makes it possible to present his findings in terms of several alternative output formats and at several alternative levels of aggregation. Thus, MITRE's system cost data base and electronic system cost model are,

*Mission equipment, because it is usually much larger than the other cost elements, is normally subdivided into major types in this summary format: sensors, communications, data processing, displays, aerospace vehicles, etc.

for instance, organized around an input format which stresses the major subsystems with a separate element for "General System" costs which cut across several or all subsystems. The first level subsystem breakdown is as follows:

General System

Data Processing

Data Presentation

Communication

Data Acquisition

Aerospace Vehicles

Computer Programs

Personnel

Facilities and Support

Four further subdivision levels are provided. Thus, for example, the Data Processing Subsystem portion of the input format is subdivided as follows:

Data Processing Subsystem
- Mission Equipment
  - Development, Test, and Evaluation
    - Analysis and Design
    - Fabrication for Test
      - Mockups, Prototype and Other
      - Develop Tool and Test Equipment
    - Test and Evaluation
  - Procurement and Installation
    - Prime Equipment
      - Mission Hardware
      - Special Tooling
    - Data
    - First Destination Transportation
    - Installation and Checkout
  - Initial Spares
    - Spares
    - Transportation of Spares
- Aerospace Ground Equipment (AGE)
  - Development Test and Evaluation
  - Procurement and Installation
    - Equipment
    - Data
    - First Destination Transportation
    - Installation and Checkout
  - Initial Spares
    - Spares
    - Transportation of Spares
- Replacement Maintenance and Rentals
  - Materials and Services
    - Follow-On Spares
    - Transportation of Follow-On Spares
    - Equipment Replacement
    - Subcontract Maintenance
  - Rentals

4.7 Summary

Cost classification is a methodological tool which, if properly utilized, can facilitate the analysis and decision-making processes relative to the selection of military systems.

Numerous criteria can be referenced in developing a cost classification scheme that, on the one hand, will guide the collection of cost data and that on the other hand, will serve as an output format for displaying the findings or results of a particular cost study. The choice of a particular cost structure is usually influenced by two opposing forces. First, there are many compelling reasons for using standardized cost structures from system to system and from project to project. Second, the peculiar constraints, characteristics or objectives of a particular costing project often seem to favor a custom tailored cost structure especially formulated to suit these peculiarities.

There are no iron-clad, objective guide-lines that can be referenced to dictate the precise mixture of standardization and variation that should prevail in the cost structure of a given study. In compromising the issue in day-to-day operations two principles are paramount. First, cost classification, like any other methodological tool, exists to service, not to stymie, the analyst and decision-maker. Second, even under the most special circumstances a standardized or generalized cost structure can serve as a frame of reference, as a point of departure, for the development of a cost structure specially tailored, to suit the needs of a given system. Because of the substantial benefits to be derived from standardization, the cost analyst should feel obliged to justify major deviations from a standardized structure where one exists.

FOOTNOTE

	Page
[1]Department of Defense, <u>Cost and Economic Information System,</u> (July 1964)	66
[2]Detailed definitions for these elements is provided in: M. V. Jones, "A Generalized Cost Structure for Electronic Systems," The MITRE Corporation, TM-3299 (May 1962). Details on the cost formats and on other features of the MITRE Cost Model are provided in: T. J. Jannsen, H. Glazer, J. C. DesRoches, "User's Manual for the Computerized Electronic System Cost Model," The MITRE Corporation, TM-3651 (July 1963).	67

CHAPTER 5

PLANNING THE COSTING EFFORT

5.1 The Time Constraint

Almost invariably the cost analyst has less time than he would like to make a thorough and reliable cost estimate. Normally the cost estimate is only one input to a broad system analysis effort, and the cost analyst has little to say about the deadline of the overall project. Usually such deadlines are governed by the requirements of the client. Under some circumstances the cost analyst may be free to decide whether or not he will participate in a project. His decision to refrain from participating will usually be based on the position that only a very poor cost estimate could be compiled in the limited time available and that it would be better to ignore economic considerations as one of the decision criteria rather than to risk being misguided by grossly unreliable cost data. However, if he decides to participate, the cost analyst usually has to accept the time constraints of his client.

Since the cost analyst normally has less time than he would like to do his part of the task, it is appropriate that he give serious consideration at the start of a project as to how he can most profitably employ his time. The matter of using limited time wisely can be viewed from several perspectives. One basic decision concerns the amount of time that should be spent on "pre-costing" activities vs. actual cost estimating and analysis. These pre-costing activities cover the conceptual-technical-administrative ground-rules of the costing phase of the project. They concern the type of questions raised in Chapter 2 concerning the purpose of the estimate, including how "cost" will be defined for the particular project, what will be the scope of the cost analyst's responsibilities,and how important are such matters as precision, consistency, sophistication of method, etc. They also concern the amount of time that will be spent in describing the system(s) to be costed as discussed in Chapter 3 and the problems involved in spelling out the cost structure as discussed in Chapter 4. How these matters are decided may determine whether or not the cost analyst wants to participate in the project. Unfortunately, there are no hard-and-fast rules for deciding how much time on a given project should be spent on these pre-cost vs. the costing tasks. However, as cautioned previously, it is unwise to slight the pre-cost tasks since historically many estimates have gone wrong because these pre-cost tasks were dispensed with too quickly.

After the analyst has resolved these pre-cost tasks, including a suitable structuring of the elements to be costed, he has next to decide how he best can allocate his limited time to gathering and analyzing data relative to each of these elements. Rarely will it be advantageous to distribute his time equally among all cost elements, and, when it is not, he must decide which ones he will stress and which ones he will slight.

In the process of deciding how he will allocate his limited time researching the different cost elements, the analyst should gather enough preliminary information to assess the various cost elements from at least the four points of view discussed in the four sections of this chapter that follow. There are several ways he can make these preliminary assessments with only a modest investment of time. One, if he is an experienced analyst, he can draw upon his own reservoir of experience concerning past costing projects that on preliminary review seemed to have been similar to the system he is presently trying to cost insofar as the criteria that follow are concerned. If he does not have extensive experience he should seek the counsel of more experienced analysts in deriving these initial impressions. Even if he is experienced, it will pay him to cross-fertilize his own judgment with other specialists assigned to the project, including experts in other disciplines. Finally, as in describing the system (Chapter 2), he should regard this task of allocating his time wisely as a continuing responsibility throughout the study, not as a one-time decision to be made at the start of the project.

5.2 Relative Magnitude

First, he should make a rough preliminary estimate either of the dollar or percentage contribution of each major cost element to the total system cost. All other things being equal, the amount of time spent in researching a cost element should increase with the magnitude of that element's estimated value. Thus, anticipated large cost elements should be studied more carefully than small ones, since the same percentage error in a large cost element will distort the total cost estimate more than will a similar error in a small cost element. For instance, all other things being equal, more time should be spent in researching cost element A than B under the following circumstances:

Cost Elements	Anticipated Value (Millions of Dollars)
A	$60
B	3
C, D, E, etc.	37
Total System Cost	$100

A practical instance of this above principal is to be found in the case of mission equipment. For most systems mission equipment is, by far, the largest cost element; in some cases mission equipment costs are almost as large as all other system costs combined.

5.3 Potential Variation

Second, to the extent that time and data permit, the cost analyst should make a preliminary assessment of the potential variation that may be encountered in the estimated value of at least the major cost elements. This variation has two facets. One occurs when costing several alternative configurations of a system and concerns the relative sensitivity of a system's total cost to changes in the values of a system's performance parameters. The more cost sensitive is a particular parameter, the more study it should receive.

The other type of potential variation can occur when costing either a single or multiple configuration(s) of a system. This variation is a function of the uncertainty surrounding the value of an element and is measured by the dispersion about some measure of the estimated value of the element. All other things being equal, the greater the uncertainty - the greater the anticipated dispersion about the estimated value - the greater the amount of time that should be spent in researching that cost element. Stated correlatively, the analyst should not spend a lot of time researching those costs that he can establish with reasonable certainty at the beginning of the study. Thus, all other things being equal, more time should be spent in researching cost element E than F under the following circumstances:

Cost Element	Estimated Value (Millions of Dollars)	Anticipated Dispersion (including 95% of all cases)
E	$55	$40-55-150
F	$55	$50-55-60
G, H, I, etc.	$90	$60-90-115
Total System Cost	$200	

5.4 Research Pay Off

Third, and among the most important, the analyst should make an appraisal of the relative ease or difficulty he will encounter in trying to obtain useful data to reduce the anticipated dispersion about the estimated values of his major cost elements. All other things being equal, the more tractable the research problem appears, the more it will pay to devote the time to do that research. For instance, under the following circumstances, it would be preferable to research cost element R rather than S:

Cost Element	Anticipated Value and Dispersion (Millions of Dollars)	
	Before Research	After Research
R	$30-55-90	$50-60-65
S	$30-55-90	$35-60-85
T, U, V, W, etc.	$40-90-130	

The above point has particular application in costing advanced systems in that the search for useful data is sharply subject to the law of diminishing returns and it is hard to reduce uncertainty and dispersion beyond a certain point. For instance, whereas it might be profitable to spend 10 hours research analyzing the findings of a previous, exhaustive study of an analogous cost element for a similar type system, another 80 hours of research going beyong the findings of this previous study might yield no additional data that could further reduce the anticipated dispersion.

In attempting to make this research-tractability assessment, the analyst should try to pinpoint the factors that make for the uncertainty surrounding the various cost elements. Thus, in some cases uncertainty may be due to the fact that basic government and industry accounting records are presently not well organized to provide good information on a particular type of cost. For instance, until very recently, certain research and development cost elements were so characterized. By contrast in other instances, the analyst may find that the basic raw data are readily available from some accessible industry or government source, but that no one previously had a need to extract or integrate them.

5.5 Covariance Between Elements

The greater the degree of covariance between two elements, the more likely is it to pay to research the costs of those elements. This presents another reason for thoroughly researching prime mission equipment costs since frequently certain other important costs are calculated as per cents of initial investment mission equipment costs, i.e., initial and follow-on equipment spares, AGE, data (manuals, etc.). Hence, the more we can reduce uncertainty relative to prime mission equipment, the more we will reduce uncertainty relative to spares, AGE, manuals, etc.[1]

5.6 Establishing Levels of Aggregation

One particular aspect of the time allocation problem deserves special consideration, namely, the level of aggregation at which each major type of cost will be estimated. In other words, the analyst must decide how deeply he will probe into lower level or sub-element costs for each major element of cost.

This level of aggregation decision is rel·vant to the time allocation problem for two reasons: generally, the deeper the analyst explores sub-element costs:

a. the greater the time he will require to complete the estimate,

b. the clearer, more accurate picture will he get of the next higher aggregation of that particular kind of cost. In other words, a study of minor element costs is one means of firming up an estimate of major element costs.

This level-of-aggregation issue is important in costing military systems because it suggests a possible difference in the methodology of costing developments within the state-of-the-art vs. those beyond the state-of-the-art.

All future estimating, including cost estimating, is done by analogy. In other words, the only way to cost something new is to relate some of its major characteristics to similar previous experiences on which a store of knowledge has been accumulated.

An essential difference in costing a development within the state-of-the-art and one beyond the state-of-the-art is in the level of detail at which the estimating relationships or analogies should be sought. When the objective is to estimate the cost of an element involving a technology within the state-of-the-art, one can find comparable performance-design-resource-cost relationships, based on historical or projected analogies, at a relatively high level of aggregation. In other words, when a requirement is within the state-of-the-art, it is normally possible to estimate its cost relatively readily by drawing upon a reservoir of official and unofficial planning and cost estimating relationships that relate performance to design to cost, thus obviating the need to examine the specific lower level resource inputs needed to attain this capability.

On the other hand, by definition, such high-level-analogies are lacking when the objective is to cost a technological advancement beyond the current state-of-the-art. The historical relationships established for lesser performance capabilities cannot be assumed to apply to a new and greater performance capability. However, as discussed in Chapter 3.4.3., technological advancements in substantial measure require new combinations of established techniques at the subsystem, subassembly and component levels. Therefore, the costing of technological advancements can be approached systematically by locating and consolidating analogies or estimating relationships at lower levels of aggregation.

To generalize, whereas it is relatively safe to abridge the performance-design-resource-cost translation when costing an element involving state-of-the-art technologies, the more advanced beyond current technologies is a new system element, the more it behooves the cost analyst to inquire into the specific resource implications of the new requirement.

A hypothetical example will illustrate the above point. In this example the relative sophistication of a computer technology is indicated by the symbol X_1, X_2, X_3, X_4, X_5, ... Xn, where X_2 is more sophisticated than X_1. It is assumed that current technology has produced computers with capabilities of X_1, X_2 and X_4 and that reliable data indicate that annual maintenance costs for each of these machines approximate between 10% and 15% of their initial investment costs. In this case if the objective is to estimate the annual maintenance cost of a machine with X_3 capabilities, it would be presumptious, but not rash, to use a factor of 10-15% without examining in detail what would actually be involved in the way of men and materials to maintain X_3. On the other hand, it would be fool-hardy to estimate the annual maintenance cost of a computer with X_{10} capabilities, without inquiring into the fullest detail that available time and data permit relative to the types and quantities of resources that would be required to maintain the X_{10} computer.

More concrete examples drawn from actual costing studies could also be cited to illustrate the point. For instance, for purposes of advanced systems costing, to estimate the cost of housing and provisioning a complement of military personnel in conventional quarters at a new base, it is normally justifiable to use a very highly aggregated CER of $X per man without identifying in detail the specific accomodations they will need. Or in costing a new command and control system which involves the use of KC-135 airplanes as an airborne command post, it may be quite acceptable to use an official Air Force factor of $Y per flying hour to estimate the annual maintenance costs of servicing these planes. On the other hand, to estimate the cost of provisioning a similar complement of military personnel on a Moon Base would require a much greater detailing of the specific accomodations that they would need. Or to estimate the annual maintenance cost of the spacecraft to fly them there would require a relatively close inquiry into the specific types and quantities of resources to perform such maintenance.

The practical importance of this level-of-aggregation principal is twofold. One, to achieve a given degree of accuracy, technological advancements lying beyond the current state of the art must be costed at a lower level of aggregation than those lying within the state-of-the-art. Two, if a particular project requires costing a significant technological advancement and if it is very important to minimize the uncertainty surrounding the cost of this element, the way to do so is to seek estimating relationships at the subsystem, subassembly, and major component level.

Frequently, of course, the analyst cannot get such lower-level detail; it is often hard to identify such lower-level analogies. When he is faced with this contingency, the analyst should realistically face up to the fact that his estimate substantially must be a guess, and, like most guesses, unless he is lucky, he is very liable to be seriously wrong. For when he cannot identify lower-level analogies, his sole recourse is to take performance-to-cost relationships for a state-of-the-art technology and intuitively extrapolate them to cover beyond-the-state-of-the-art technology. Besides being subject to serious error, this process, because it is so basically implicit, suffers from the shortcoming that the analyst finds it very hard to learn either from his good guesses or bad ones.

5.7 Summary

Before he invests substantial time in collecting and analyzing data for each of the various cost elements in his total cost structure, the cost analyst should make a preliminary survey with the objective of securing "rough-cut" or approximate type information on the following:

a. The relative magnitude of the various elements. More time should normally be spent in researching anticipated large cost elements than small cost elements.

b. The potential variation of the various elements. The larger the potential variation, the greater the amount of time that should be spent in researching the element. This variation may be of two types: one, the cost sensitivity type in which total system cost is related to changes in the value of key performance or design characteristics; two, the potential dispersion in an element's cost due to uncertainty.

c. The potential research pay-off. The more tractable the uncertainty problem is to research and inquiry - the more promising it appears that a given amount of research effort will firm up our knowledge of an element's cost - the more justifiable is it to make that research.

d. The extent of covariance between several elements. The greater the covariance between elements, the more likely is it to pay to thoroughly research these elements, especially the largest and independent variable.

As a general principle, to achieve a given standard of accuracy, technological developments lying beyond the current state-of-the-art should be costed at a lower level of aggregation than those lying within the current state-of-the-art.

FOOTNOTE	Page
[1]The mathematics for explicity taking each of the above criteria (5.2 - 5.5) into account in making an estimate has been worked out by J. R. Miller of the MITRE staff. In addition an operating computer program to implement the mathematics has been written. The entire technique will be incorporated into a Ph. D. thesis now under preparation at the Massachusetts Institute of Technology.	77

CHAPTER 6

SELECTING AND COLLECTING COST DATA

6.1 Shortcomings of Available Data

6.1.1 General

Chapter 3 emphasized how very important it is to accurate system cost estimating to identify accurately the types and quantities of resources to be costed. The second requisite to accurate system cost estimating is to accurately determine the prices per unit to be used in costing each of these resources.

Since all future costs are estimated via analogy to some previous cost experience or projection, a major task confronting the estimator is to decide where to look for the most appropriate analogies. Accordingly, one of the most important functions of system cost methodology is to guide the estimator in seeking such analogies -- to provide ground rules relative to cost data inputs for the new estimates.

The decision relative to cost data inputs is difficult for at least three reasons:

a. Until recently there has been a general shortage of historical data with a system orientation.

b. Available data have frequently been of questionable validity and of doubtful comparability over time.

c. Available data have frequently been of limited relevance to future cost estimating because the technological requirements of new systems have often differed markedly from those of past systems; that is, the past and future systems have not been completely analogous.

6.1.2 Scarcity of Data

First, military system costing, as a relatively new discipline, has suffered from a general shortage of historical data. Although the military services and industrial contractors have maintained comparatively detailed financial and related records on military contracts for many years, relatively few of these voluminous data, until recently, have been classified on a system basis. One reason for this is that in some areas, like complex military electronic systems and space systems, the systems have been relatively few in number and relatively recent in origin. Since these systems take five to ten years to run their course, system cost analysts have frequently been obliged to estimate the cost of an important element of a new system on the basis of only one, two, or several more or less analogous cost experiences in the past.

6.1.3 Qualitative Shortcomings

Second, available data have suffered from serious qualitative shortcomings. In this initial period government and industrial cost reports and accounting records have been in the process of development; and only recently has the pattern of a comprehensive, standardized reporting procedure begun to emerge. Therefore, for many of the systems introduced five to ten years ago the cost records are in some important particulars lacking, in others incomplete or incomprehensible, and in most cases of limited comparability with the records of more recent systems.

A somewhat related problem is that many cost reports have not been properly structured to provide the kinds of data needed for advanced system cost analysis. This has happened beca e these reports have been designed primarily to serve other purposes such as monitoring contractor performance on current contracts.

6.1.4 Relevancy Problems

Third, available data often have provided a dubious future estimating base because the performance and design characteristics of new systems have sometimes differed markedly from those systems for which an adequate and valid cost data base has existed. Thus, even ample and reliable data on a past system having X level survivability, having a computer with a Y data processing rate, and an airborne vehicle capable of Z speed are of limited usefulness in costing a future system requiring a 5X level of survivability, a computer with a 10Y data processing rate, and an airborne vehicle capable of 3Z speed.

6.2 Using Available Data to Best Advantage

6.2.1 Need for Multiple Inputs

For two reasons the cost analyst should explore widely in seeking analogous cost experiences as a base for his future cost estimates. First, if the cost analyst relies on one or two observations as his estimating base, he will find it extremely difficult to determine whether these observations provide a representative sample. If they are not representative, he runs a risk of serious error if he uses them as a future estimating base. In other words, normally no single prior experience or projection should be taken as 100% applicable to a new costing situation. Even in cases in which the future element configuration completely corresponds to some past configuration, it does not mean that, *ipso facto*, the future costs will correspond exactly to the past. As a bare minimum, the future situation should be examined for such possibilities as price level changes or learning curve phenomena. If different industrial contractors may be used in the future, different pricing policies and productivity coefficients should be allowed for. Even the same contractor from one period to the next may change his pricing philosophy. Similarly, in the realm of military costs, such factors as military pay and allowances are subject to Congressional amendment, and staffing patterns for performing certain jobs may change.

6.2.2 Analogies at the Element Level

Just as no single historical datum is completely relevant and sufficient for costing a new requirement, similarly great masses of data might be admitted on a limited relevancy basis. Practically, this means that in seeking cost analogies the cost analyst can profitably look beyond the one or several prior systems whose end missions, general requirements, and general configurations most closely resemble those of the new system he is costing. It must be remembered that the costs of large, complex military systems are usually estimated by summing the costs of their numerous constituent elements. And great similarities will often be found in the constituent elements at the subsystem, major function, and major component level among systems which differ substantially in terms of their end missions, general requirements, and general configurations.

The logic of seeking broadly for relevant analogies at the cost element level could be illustrated by many examples. A few will be cited.

a. The cost of transporting a military officer overseas is likely to average $750 per man whether that officer is to be attached to a weapons system or a command and control system. (In practice, this cost is likely to vary greatly from situation to situation. The determining factors, however, are not the type of systems to which a man is assigned, but where he is located geographically, his rank, and whether he is single or married with dependent travel authorized.)

b. A support-service facility -- like a barracks, mess hall or general administration building -- will normally in a given environment entail similar costs whatever the type of system in which it is employed.

c. The costs of maintaining a given off-the-shelf computer should be similar whether the computer is used in a command and control system; a weapon system; an Army, Navy, Air Force or NASA system.

d. The hourly operating and maintenance costs of a C-135 airplane are likely to be similar whether the plane is used for transport purposes or as an airborne command post.

Recapitulating, rather than seeking to pinpoint the one most closely analogous prior observation, the cost analyst should aim for multiple inputs of various relevancies and should consider each of these observations in reaching his estimate of the cost of the new element.

However, if he is to carry out this prescription effectively, the cost analyst must take account of two other considerations. One, if he is to consider multiple data inputs, he must have a method for evaluating and weighting each of these inputs in terms of its applicability to the new cost estimate. Chapter 7 of this paper will discuss this issue.

Second, in separately considering various sources of historical and projected data as potentially pertinent or analogous to the new cost estimate that he has to make, the cost analyst must balance the expected payoff of such research against the man hours required to do that research. In the last analysis, the cost analyst must rely substantially on his judgment and experience in deciding to explore one potential source of data as opposed to another. However, the type of criteria advanced in Chapter 5 for allocating research time should help him in formulating and verifying his judgments.

6.3 Using Expert Opinion As A Data Source

Concurrently with his efforts to increase the number of data inputs at his disposal, the cost analyst should strive to include more reliable and relevant types and sources of data in the base for his future cost estimates.

6.3.1 Improvements in Reporting

New cost reporting procedures established in recent years by the Department of Defense and the Air Force have improved both the clarity and completeness of the formal system cost base available to the analyst. Equally important, these new procedures have fostered a greater comparability of historical cost data from one time period to another and from one program element (system) to another. One result of this trend toward standardization has been to facilitate the search for cost-estimating relationships pertinent to a new estimate.

6.3.2 Rationale for Subjective Inputs

To further improve the relevancy of the data inputs which he uses as a base for estimating the costs of future systems, the cost analyst increasingly must go beyond the field of objective, historical statistics to include among his data inputs a whole range of subjective projections. He should do this because these subjective data sources, such as previous advanced planning cost estimates of other new systems, still under development, and the expert opinions of specialists in various equipment and subsystem areas, frequently can provide a more relevant basis for costing the advanced technologies of new systems than can the historical statistics covering the costs of older technologies and systems.

This recourse to projections or expert opinions as a base for deriving other projections, estimates, and opinions is nothing new. In recent years Bayesian statistics with its emphasis on subjective probability has gained much support. And, of course, the businessman and market analyst have traditionally followed this principle in forecasting the future sales of a company's products. That is, in forecasting the sales of his company's product, a market analyst will not only consider the objective, historical records of the company's past years' sales. He will also give important weight to the separate opinions of top-ranking economists as to what the gross national product will be in the subsequent year, and also to the opinions of the company's marketing and production specialists relative to the projected competitive position of the company in the industry in which it operates.

6.3.3 Methodological Problems

The methodology of using expert opinions and other subjective projections as data inputs to future cost estimating is largely undeveloped. Hence, the comments on this subject in this document will be suggestive only.

For one thing, it is pertinent to note that the problems of the system cost analyst in handling these types of inputs are methodologically quite similar to those encountered by specialists in other disciplines -- the business decision maker, the economist, the market research analyst, the sociologist, the political scientist, and the behavorial scientist in general.

Illustrative of the types of problems that confront the analyst are:

a. The establishing of formal or informal criteria for selecting the experts whose opinions are to be solicited.

b. The formulating of the precise question(s) to be put to the expert(s) and, where multiple experts are involved, the standardizing of the procedure for presenting the questions in order to minimize misinterpretation, deliberate bias, and otherwise non-uniform or unmeaningful responses.

Since the problems of the cost analyst in handling expertise are methodologically akin to the interview problems faced in the other disciplines references, these types of problems will not be discussed here.[1] However, Chapter 7 will discuss a third, related task, namely, how to devise systematic methods for evaluating the responses received from the various experts against each other and also for determining the relevancy of each against various historical data as pertinent to the new cost being estimated.

6.4 Sources of Data

This paper will review only illustratively the various sources of historical and projected cost data useful to the system cost analyst. A comprehensive review and evaluation of specific official and unofficial data sources will be reserved for a subsequent companion study to the present document.

Government and industry reporting, accounting, and information systems provide the source of most historical data:

a. There are, in the first instance, official reports that industry is required to file with the cognizant military office or that lower echelon military offices file with higher authority. In the former group are the Contractor Cost Reports that all major contractors are required to file with the appropriate Air Force procurement office that, among other things, summarize the cost experiences of the company on the designated contract during the preceding year.

b. Over and beyond the formal reports, basic accounting records, both government and industry, provide considerable unpublished, historical data that can be tapped during the course of personal visits to the respective office, provided clearance for access to this material can be arranged.

c. Additionally, special historical studies on particular systems are sometimes prepared by various offices of the Air Force, by industrial firms, or by non-profit organizations such as RAND, AEROSPACE, or MITRE.[2]

d. Numerous official compendiums either summarize data that appeared in the official recurring reports or index the various reports that are available. Illustrative of the former are the Air Force's USAF Planning Factors (Peace Time and War Time), AFM-172-3 and USAF Statistical Digest, SSU-23. Also various Air Force manuals summarize cost, design and related information on state-of-the-art equipment, e.g., Military Handbook, Electronic Communication Equipment (4 Volumes), MIL-HDBK-161. An index of Air Force reports is provided by List of Recurring Reports, SS-U26.

e. Finally, numerous official and private catalogues plus private information services and trade journals contain a wealth of cost and related data covering particular systems, equipments, and state-of-the-art technology. In the former category are the General Services Administration's, Gille's Associates', and Adams Associates' catalogues on electronic data processing equipment. In the latter category are Aviation Week, Missiles and Rockets, Datamation, etc. plus the Defense Marketing Services (Market Intelligence Reports).

Sources of projections and expert opinions relative to future or prospective system cost data are equally varied:

a. The Contractor Cost Reports previously referenced as a useful source of historical data are similarly valuable as a source of contractor estimates of the cost to complete the contract.

b. Prior to these in the chain of official documents in the procurement cycle are the bid proposal reports. One of the advantages of the bid reports is that they provide a basis for securing a consensus of expert opinion on the cost of meeting a new requirement.[3]

c. Once again, personal visits to industry or government offices can sometimes extract unpublished details lying behind these official reports.

d. Similarly, experts working for industry, government, universities, and not-for-profit organizations are very well versed with potential new products and new technologies, and they often can give the cost analyst valuable opinions relative to the resource implications of future developments in their specialized fields.

e. The official Department of Defense and Air Force reporting systems, such as Proposed System Package Programs (Section 11), provide detailed cost estimates covering systems and programs submitted to higher echelons for approval.

f. There is an increasing number of advanced system cost studies prepared by the Air Force, by industry (solicited or unsolicited), and by non-profit organizations such as RAND, AEROSPACE, and MITRE.

g. Trade journals and private information services, as cited previously in this section, are a source of projections and expertise just as they are a source of historical data.

6.5 Data Base Systems

Practically all organizations that have established system cost analysis departments have found it advantageous to establish what are known as Data Base Systems or Data Banks.

A Data Base System is a technically and administratively centralized system for handling major empirical functions associated with costing military systems.

Simply stated, the objective of any Data Base System is to provide the cost analyst with both more and better quality data and to provide this data more quickly than would be possible without such a system.

In practice, the degree of formality characterizing the Data Base Systems of existing system cost analysis organizations varies considerably. The major features of the MITRE Data Base System, one of the more formalized of the existing systems, are the following:

a. A comprehensive and consistent system for the determination of types of data to be gathered.

b. A systematic and efficient means of collecting and updating such data.

c. An easy method for the entry of such data into the Data Base.

d. A formal method of evaluation, validation, categorization and storage of the data.

e. A quick means of retrieval for ultimate use.[4]

The Data Base should properly serve not only as a central repository for the collection and dissemination of the documented, historical portion of system cost data, it also can function as the focal point for identifying knowledgeable, external sources of relevant information.

One of the important practical consequences of a centralized Data

Base System is that it tends to formalize and standardize the documentation of departmental cost studies. A highly sophisticated Data Base System will require the cost analyst to document relatively specifically how he arrived at his cost estimates, including an identification of his sources of primary and secondary data, a detailing of the statistical manipulations he performed on these data, and an explanation as to why he selected these data sources and statistical techniques as opposed to others. To the extent that it promotes these practices a formalized Data Base will contribute to attaining the systematized, explicit approach to cost analysis advocated in Chapter 1. Accordingly, a formalized Data Base System can be a most useful step in securing the regular "feedback" so essential if system cost analysis is to become more of a science and less of an art.

6.6 Cost Estimating Relationships

6.6.1 Definition and Classifications

Up to this point this chapter has discussed particular historical cost experiences or projections as data inputs or analogies for estimating the future cost of a new system element. Chapter 7 will consider the mechanics of melding these heterogenous bits of evidence into an estimating tool specifically tailored for calculating the future cost of a particular cost element of a particular system.

This section, on the other hand, will discuss briefly the generalized cost estimating relationship, hereafter referenced as a CER. Simply defined, a CER is a generalized statistical distillation of multiple cost experiences covering a defined type or area of cost. Frequently, a generalized CER serves as one of several or many inputs in estimating the cost of an element of a particular system.

CERs may be differentiated by the type of cost determining variables, as follows:

a. Cost related to some physical resource, e.g. -- building construction cost = $15 per square foot.

b. One type of cost related to another, e.g. -- Annual Operating Cost (Mission Equipment) = 15% of Initial Investment Cost (Mission Equipment).

c. Cost related to some performance characteristic, e.g. -- Electronic Computer Central Complex Initial Investment Cost in Dollars

$$\log_{10} C = 6.44 - 0.980 \log_{10} SCT + 0.064 \log_{10} CAT$$

where C = Cost of central complex in dollars

SCT = Storage cycle time in microseconds

CAT = Complete add time in microseconds

These several basic types of CERs may be further differentiated into several degrees of complexity or sophistication. The simplest CERs are linear, proportional relationships between cost and one cost-determining variable such as the building construction cost example cited in the preceding paragraph. More complicated CERs depict various types of non-linear relationships between cost and two or more cost-determining variables such as the computer equipment CER cited above. Most of the generalized CERs actually used in costing military systems are linear-proportional relationships between cost and one cost-determining variable, usually cost and some physical resource or parameter. (As used here, the term "physical" resource is broadly defined to include human resources such as engineering man hours as well as inanimate resources such as buildings and equipment.)

Generally there is a positive correlation between the number of observations and the validity of the estimating relationship, i.e., the relative accuracy with which the statistical estimating relationship actually measures the phenomenon it is depicted to measure. However, any number of individual data points, including both objective (historical) and subjective data inputs can be used as the base from which to derive a generalized cost estimating relationship. Again in point of experience, most generalized CERs developed to date and actually used in military system costing are based predominantly, almost exclusively, upon historical experience.

One additional differentiating characteristic among CERs should be noted; namely, the level of aggregation. A large variety of aggregation levels for a given type of cost can be developed. For instance, at a high aggregation level, it may be generalized that Military Pay and Allowances = $5,000 per man per year (this $5,000 per year figure assumes a ratio of one officer to five airmen). A step lower in aggregation would be: Military Pay and Allowances (Officers) = $10,000 per man per year and Military Pay and Allowances (Airmen) = $4,000 per man per year. Still lower aggregation levels would differentiate both officers and airmen into different rank, skill, geographical assignment location, and other such cost-determining categories.

6.6.2 Advantages of CERs

The preceding point appropriately leads to the next question, the advantages of using CERs. The most obvious advantage of CERs is the tremendous savings they can provide in the time required to complete an estimate. In effect, a CER makes it possible to estimate a highly aggregated future cost, e.g., equipment maintenance costs, without a detailed identification and costing of each of the specific resource inputs to this future cost. The alternative to using a CER would be a low-level-of-aggregation direct measurement by which the analyst estimates a high-level-of-aggregation future cost by identifying, tallying, and pricing in detail each of the specific types of resource inputs to a new system element. Thus, the availability of a generalized CER makes it possible in individual costing studies to reduce greatly the time spent in gathering and compiling data. In a matter of hours, sometimes even in minutes, by means of a CER, an analyst can estimate a future cost that would require days or even weeks to estimate through direct measurement. Thus a direct measurement of equipment maintenance cost would have to cover the replacement of equipment, follow-on spares, maintenance personnel (military, government civilian, contractor), transportation of equipment and spares, updating maintenance manuals. Additionally, it would be necessary to further subdivide the above general types of maintenance costs into types of equipment to be maintained, types of personnel to be employed, etc.

Sometimes a CER will also provide a more accurate, reliable basis for estimating a future cost than a direct measurement. A well-developed CER is derived from a wide-coverage, carefully documented, objective, after-the-fact analysis of representative available data. On the other hand, direct measurements frequently are the product of a fragmentary,hastily compiled survey that fails to cover representatively and in depth the cost element being studied. It is especially difficult to make adequate direct measurements of total life-cycle costs in the advanced planning stage of a system's development long before the physical and operational characteristics of the system have been defined in detail.

6.6.3 Limitations of CERs

Are there any shortcomings or limitations in using CERs; when is it advisable to use a different estimating tool; and what are such alternative tools?

In the first place, it is not always possible to use a CER because for certain types of cost, generalized CERs have not yet been developed. As an example, a shortage of usable data has made it difficult to develop reliable CERs for estimating research and development costs.[5] Similarly, difficulty in marshaling available data and the heterogeneity of display equipment have hampered efforts to develop good CERs for electronic display equipment.

Second, CERs have some limitations even in cases in which substantial effort has been expended in developing relatively sophisticated CERs, as in the case of electronic computers.[6] For one thing, the generalized CER on computers covers many manufacturers' equipments and various models from each manufacturer. It, thus, by definition depicts an average relationship. If the analyst happens to be costing an off-the-shelf computer and he knows the particular manufacturer and model required, a catalog price, such as listed by the General Services Administration catalog, will provide a more accurate estimating base than would a generalized CER.

Similarly, when the assignment is to estimate an element whose technology lies beyond the state-of-the-art, a CER, being based predominantly or exclusively on historical experience for state-of-the-art equipment. loses some of its relevance.

6.6.4 <u>When To Use CERs</u>

Acknowledging the above qualifications, much can still be said in favor of a generalized CER as an input for estimating both state-of-the-art and beyond-the-state-of-the-art elements. Frequently when the analyst has knowledge that a state-of-the-art development is involved, he may not know the particular manufacturer and model number of equipment required.

This is especially likely to happen in an advanced planning study. In such case, a particular catalog price may be too specific whereas a generalized CER by giving the average or representative price may offer a useful working compromise. As a bare minimum, the CER would serve as a useful sense check of an estimate derived through catalog sources.

The case for the usefulness of a generalized CER is even more compelling when the task is to estimate the cost of an element whose technology lies beyond the state-of-the-art. In the words of David Novick, the more "futuristic" is the requirement, the more important it is to study history in search of useful analogies.[7] The rationale for this point of view is stated by Simon Kuznets in a somewhat broader context. Writing on the methodology of long-run economic projection, Kuznets notes that two conditions are always necessary to any kind of projection. One is that there must be an identifiable relation between the future and the past. Two, there must be a minimum of order in the past that can be translated into some specific pattern for the future.[8]

In the case of military system analysis when costing a beyond-the-state-of-the-art requirement, the generalized CER provides the analyst with a frame of reference, a useful starting point. The generalized CER, if it has been reliably derived, epitomizes history, and if the analyst rejects history, he is almost completely bereft of a base from which to begin. The essential precaution that the analyst must, of course, observe is that, when a requirement is beyond the state-of-the-art, the generalized CER must be regarded as one important data input among several or many rather than the one and only input or estimating base.

6.7 Summary

The reliability of a completed system cost estimate is vitally dependent on the validity and relevance of the cost data inputs used to derive the estimate. Accordingly, one of the most important functions of system cost methodology is to guide the cost analyst in selecting the appropriate types and quantities of data he needs to estimate the costs of his system.

One of the reasons that system cost estimating has been difficult in the past is because historical cost data classified on a system basis have frequently been sparse, incomplete and non-comparable from system to system and from one time period to another.

In costing a new system the cost analyst should draw upon as extensive and as comprehensive a data base as possible. In seeking to expand his data base he should look for analogies at the system element level -- subsystems, major activities, and major components. He should extend his search at the element level to incorporate systems differing in end-mission, general requirements, and general configuration from those of the new system he is costing.

The dynamic character of military technology makes it imperative that the cost analyst look beyond the realm of historical statistics to incorporate subjective, expert opinion into his cost-estimating base.

The cost analyst should be eclectic in searching out specific data sources for a particular cost estimate since there are numerous official and unofficial, formal and informal, sources of system cost data.

The generalized cost estimating relationship (CER) is an invaluable, frequently an indispensible, tool in estimating future system costs. Its main shortcoming, like that of other useful tools, is in its indiscriminate applications to problems that it was never intended to solve. More specifically, the generalized CER is almost always a useful input to a cost estimating problem. On the other hand, only infrequently is it suitable as the sole input to an estimating problem.

A centralized Data Base System can provide the cost analyst with both more and better quality data and can also provide this data more quickly than would be possible without this system. As such, it can be an importent means of securing the regular "feedback" so essential if system cost analysis is to become more of a science and less of an art.

FOOTNOTES | Page

[1] A number of standard texts discuss the methodological problems in obtaining and handling subjective, opinion-type inputs; e.g., Festinger, Leon and Katz, Daniel, Research Methods in the Behavorial Sciences, (Holdt, Rinehart, and Winston, 1953) and Lerner, Daniel and Lasswell, H. D., The Policy Sciences, Recent Developments in Scope and Method (Stanford University Press, 1959), Chapter IX, XI, XII, XIII, XVI. — 92

[2] For instance: R. L. Hamilton and T. H. Rider, Cost Estimate of Certain 416L Functions, The MITRE Corporation, TM-3040. — 93

[3] See: M. V. Jones, Bidder Cost Estimates As A Data Base Source For Advanced Systems Costing, The MITRE Corporation, TM-3538 (1963). — 94

[4] A detailed description of the MITRE Data Base System is contained in: L. R. Morris, "The Economic Factors Data Base System," The MITRE Corporation, TM-3645 (June 1963). Also see: L. R. Morris, "The Economic Factors Library," The MITRE Corporation, TM-3161-1 (January 1963). — 95

[5] The most systematic effort to develop CERs for costing R&D has been done by J. W. Noah, Identifying and Estimating R&D Costs (RAND, RM-3067-PR), May 1962. — 100

[6] CER studies on electronic computers have been completed by the following: — 100

E. I. Friedland and J. R. Miller, III, A Search for Computer Cost Estimating Relationships, The MITRE Corporation, W-6595, (October 1963).

E. I. Friedland and J. R. Miller, III, Computer Cost Estimating Relationships: User's Manual, The MITRE Corporation, W-6596, (October 1963).

L. B. Early, S. M. Barro, M. A. Margolis, Procedures for Estimating Electronic Equipment Costs, RAND, RM-3072-PR, (May 1963).

R. W. Rector, Predicting the Cost of Computing Equipment From Its Physical Characteristics, SYSTEM DEVELOPMENT CORPORATION, (31 October 1962).

U. S. Air Force, Systems Command, Electronic Systems Division, Electronic (Data Processing) CER (21 September 1962).

[7] Op. cit., p. 3. — 101

[8] Simon Kuznets in National Bureau of Economic Research, Long Range Economic Projection, (Princeton University Press, 1954), p. 11. — 101

CHAPTER 7

DERIVING THE COST ESTIMATE

7.1 Parameters of the Problem

7.1.1 Objective

Chapter 6, being concerned with the input side of the cost-estimating process, stressed the advantages to be gained in collecting many and varied types of data.

Chapter 7, on the other hand, might appropriately be subtitled "the process of converting inputs into outputs" since the primary function of this chapter will be to discuss the mechanics of melding heterogeneous data inputs into an integrated estimated cost of a new system.

The "element" has been selected as the point of reference for a discussion of output methodology since a total system is normally costed in terms of its constituent elements. In other words, this is an instance where the whole equals the sum of its parts; if the elements are properly and accurately costed, the total system cost will be correspondingly reliable.

7.1.2 Degree of Estimating Difficulty

As pointed out previously, all elements cannot be costed with equal simplicity. The precision required in the completed estimate and the time available to make the estimate are both relevant. The greater the precision required, the greater the difficulty of the estimating task. On the other hand. the greater the time available, the less difficult is it, generally, to achieve a given standard of accuracy.

The nature of the data inputs available also influences the ease or difficulty of the estimating task in several ways:

a. the larger the number of data inputs (the more ample is the estimating base), the easier is the estimating task. In other words, it is normally easier to estimate from large data samples than from small ones.

b. The more diverse is the estimating base, the more difficult is it to meld the various inputs into an integrated estimate. For instance, it is normally more difficult to integrate a historical CER with two informed opinions than it is to integrate three similar, historical experiences.

c. The presumed validity of the estimating base is also pertinent. The more accurately the available data measures the phenomena they are intended to measure, the more certainty with which these inputs can be used as a future estimating base.

d. The presumed relevance of the estimating base is similarly very important. The more closely the performance and physical characteristics of the new element resembles the performance and physical characteristics of the elements in the estimating base, the easier is it to make a future estimate.

7.1.3 A Single Data Input

If there is only one data input -- if some past experience is considered to represent a true and complete analog of the future element being costed -- the estimating procedure is comparatively simple. In essence it involves a bookkeeping transaction in which the historical or projected cost is located and transposed in a catalogue fashion as the cost of the future element.

Relatively frequently a single data input is used as the analogue for estimating the future cost of an element of a new system. The most notable instance of this practice is the use of a generalized CER, e.g., overseas travel = $750 per man transported. If the cost element represents a small percentage of the total system cost, and available evidence indicates that the cost of the particular system for this area of cost will parallel the generalized past experience, such a practice is legitimate.

7.1.4 Multiple Data Inputs

However, in many other cases the analyst must resort to multiple data inputs because: (1) no generalized CER has been developed, (2) the future cost of the new system or element is expected to differ importantly from the generalized past experience, usually because it is functionally or physically different from any previous system or element, (3) and/or the item of cost is sufficiently large and its impact on the total system cost sufficiently great that the analyst feels obliged to secure cost inputs expressly tailored to fit the new requirement.

As soon as there are two or more data inputs to a new estimate, a problem of weighting develops. In a typical, relatively simple case, if there are two current systems (A and B) whose annual operating equipment maintenance costs are regarded as being somewhat analogous to the anticipated equipment maintenance costs of a new system (C), a decision must be made on the proportionate weight to be given to the A and B experiences, respectively, in arriving at the maintenance cost estimate for system C.

Many cost estimating problems are much more complex, especially if the eclectic view of data relevance recommended in Chapter 6 is adopted. This point can be illustrated in terms of a hypothetical requirement to estimate the annual maintenance cost of a new type of computer that has many of the performance and design characteristics of numerous former, present-day, and projected computers. In this case, data inputs relative to computer maintenance costs could be extracted or acquired from government and private historical records, from contractor projections associated with new systems under development, from bid proposal (source selection) cost estimates on other advanced systems, from the "guesstimates" of few or many industry, non-profit, and government "experts", etc. If an aggressive effort were made, it would be easy to compile literally dozens of historical and projected data points.

7.2 Elements of a Solution

7.2.1 The Basic Choice

As indicated above, there is no avoiding the weighting decision when there are multiple data inputs to a cost estimate. The analyst essentially has two basic alternatives. Either he does the weighting explicity or he does it implicitly. His only choice is on the formality and rigor he applies to the task, including the documentation. A decision to ignore the problem and toweight every observation equally involves as compelling a decision on the matter of input weighting as though days or weeks were spent in devising an elaborate technique for making an explicit, methodical weighting.

The basic methodological issue drawn in Chapter 1 between an implicit approach vs. an explicit approach is nowhere more sharply focused than on this matter of input weighting. As discussed in Chapter 1, the primary reason why implicit methodology is undesirable is that when the analyst uses implicit methods to derive his cost estimate he foregoes the opportunity both for an immediate check of his estimating rationale with other analysts while the estimate is being derived and for subsequent empirical verification (feedback). An explicit procedure, on the other hand, discourages caprice in estimating costs and it provides the analyst with the opportunity both to profit by his mistakes and to benefit from his good insights.

7.2.2 Kindred Disciplines

System cost methodologists have rarely, if ever, discussed this matter of input-data weighting in any formal sense. However, in several kindred areas military decision makers have encountered the need to devise relatively methodical (impersonal) weighting schemes for handling important practical problems.

Four instances may be cited:

a. Cost/effective analysis is one of the important new tools that has been developed in recent years to lend more system and science to the process of choosing among alternative military systems and system configurations. However, one of the major tasks involved in the use of this technique is in devising criteria for defining, evaluating, and weighting one kind or attribute of system performance or effectiveness against another.[1]

b. Policy and operating levels of the Defense Establishment, both as high and low echelons, are constantly striving to impart greater objectivity to the Source Selection process of choosing military contractors. A major aspect of the research in this area is in finding more objective (non-personal) means of evaluating and weighting one bidder's qualifications against another.[2]

c. The Department of Defense is in the process of establishing a Contractor Performance Evaluation System. This system seeks to rate objectively (impersonally) a contractor's success in meeting the performance, cost, and schedule provisions of his contract. However, requirements in each of these areas are multi-dimensional, and one of the objectives of the CPE program is to provide an explicit, systematic methodology for weighting performance in each of its constituent phases.[3]

d. The Department of Defense has been seeking more explicitly non-personal criteria for determining contractor profit objectives on military contracts. To provide for a more uniform interpretation of the Armed Services Procurement Regulations (ASPR) by military procurement personnel, the Department of Defense has developed a "Weighted Guideline System". This new system seeks to spell out explicitly appropriate profit criteria and to provide weighting to be applied to these criteria under different circumstances.[4]

The task of devising schemes for explicitly weighting the data inputs to a system cost estimate is, in some respects, methodologically similar to the task of devising weighting schemes for the other military decision areas referenced above. Since system cost methodologists, themselves, have not yet established a data input weighting scheme, they would probably stand to benefit if they were to become familiar with both the problems and the approaches to weighting devised in these somewhat kindred disciplines.

7.3 Illustrative Weighting Format

7.3.1 The Advantages of Simplicity

There are two operations associated with establishing a data-input weighting scheme. One is to establish criteria for assigning weights to various cost inputs. The other is to devise formats or similar tools for presenting the weights. The latter task will be discussed first.

Although weighting schemes in general can be made quite complex, there are advantages in this case in keeping them as simple as possible, considering the time constraints that the cost analyst is usually confronted with and the difficulties in collecting relevant data. The highly uncertain nature of the input data, themselves, would belie a highly refined mechanics for processing these data.

7.3.2 Examples

The following hypothetical example perhaps typifies the simplest type of weighting format:

Objective: To establish a basis for estimating the annual maintenance costs of the mission equipment of a new system X.

Conditions: (1) The cost is to be expressed as a percentage of the initial investment mission equipment costs of system X.

(2) There are five cost data inputs to this estimate; namely, the historical annual mission equipment maintenance costs of systems A, B, C, D, and E. These historical costs have each been converted to a percentage of initial investment costs.

The advantage of a relatively simple format like the following is that it provides at least a start on a scheme for arriving systematically at a cost estimate. Such a format removes at least a part of the mystery associated with purely implicit methods of converting cost inputs into cost outputs. The format provides a partial answer to the question as to how the analyst reached his conclusions; and in so doing, it furnishes a basis for further inquiry.

7.4 Weighting Criteria

7.4.1 Seeking Objectivity

Of course, at very best, such a format is only a start on an objective weighting scheme. Two critical questions remain to be answered; namely, to take the first example, how did the analyst decide upon the weights

Data Inputs Previous Systems	Historical % Costs	Weights	% Costs x Weight
A	5	10	50
B	15	20	300
C	20	30	600
D	40	5	200
E	10	35	350

$\therefore$ Estimated Annual Operating Mission Equipment Cost of System X = $\frac{1500}{100}$ = 15%

The foregoing example can be varied to change Condition (2), the nature of the data inputs, as follows:

Data Inputs	Source	Annual Operation Cost As % of Initial Investment Cost	Weights	% Costs x Weig
1	A generalized CER covering 20 historical cost observations on somewhat analagous equipment taken between October 1960 and December 1962.	20	30	600
2	A preliminary 1963 historical cost estimate on System Y which has equipment more analagous to System X than the equipments of the systems covered by the generalized CER.	30	20	600
3	A projected estimate contained in a recent advanced planning study on System R. System R's equipment is also more analagous to System X's than that of the systems covered by the generalized CER.	15	15	225
4	Company A's opinion. Company A has done most of the R&D on the new equipment being costed.	10	25	250
5	Company B's opinion. Company B is the largest and generally acknowledged most experience in developing and manufacturing this type equipment.	25	10	250

Estimated Annual Operating Mission Equipment Cost of System X = $\frac{1925}{100}$ = 19%

that he assigned to the cost experiences of systems A, B, C, D, and E and why did he select the cost experiences of systems A, B, C, D, and E to use as analogs or data inputs to system X as opposed to the cost experiences of some other systems?

Because of the critical importance of this issue in costing a military system, it would be desirable to have completely explicit, non-personal criteria for answering these questions. Such objectivity can never be completely attained because the criteria must be applied by an analyst to fit each particular costing project, and this application cannot be completely divorced from the judgment and temperament of the analyst. However, as his ideal the methodologist should strive to devise criteria that will become increasingly insensitive to the implicit personal whims and temperament of the analyst, and that, in effect, will insure that one type of data will be weighted or rated more heavily than another under specified conditions whatever the temperament or personality characteristics of the analyst.

Illustrative of the types of criteria envisioned are the following.

7.4.2 Validity and Relevance

Each data input should be evaluated from two points of view, namely, its validity and its relevance. Relative to validity, how accurately does a piece of data measure the element or activity it purports to measure? Concerning relevance, how directly pertinent to a new system element is the cost experience of a prior or current system? Generally, the weight attached to a data input should vary directly, both with the validity and relevance of the data. A problem frequently is that data which have had their validity firmly established by substantial empirical studies are of limited relevance to a future requirement whereas a data input, such asa guestimate of a specialist in a particular technological field may be highly relevant, but lacking in any substantial confirmation of its validity.

7.4.3 State-of-the-Art

Pursuing the previous point, generally historical data should be weighted more heavily than opinion if the goal is to estimate the cost of an element whose technology lies within the current state-of-the-art. A subtle qualification is that opinion merits an important weight even when the problem is within the state-of-the-art if the source of the opinion is an acknowledged expert and he can show concrete evidence why the historical statistics do not accurately measure the element they were supposed to measure or he can present a convincing case why general price level changes, learning curve phenonema, or other considerations will alter historical experience insofar as future costs are concerned.

If the goal is to estimate the cost of an element whose technology lies beyond the current state-of-the-art, projected costs -- as defined in Chapter 6 -- gain in relative stature and weight as compared to historical statistics. The further beyond the current state-of-the-art lies the technology of a new requirement, the greater is the importance that attaches to expert opinions and projections as a data source. For instance, consider the problems involved in estimating the computer maintenance costs of a three generation early warning system of increasing technological sophistication. The historical data on the costs of the basic System A_0 will be heavily weighted in estimating the costs of System A_1. However, in estimating the costs of System A_2, the weight attached to the historical data on the basic System A_0 will decline in relative importance, and substantial weight will be attached to the projected costs of System A_1.

assuming that no historical data are available on A_1 when A_2 must be cost estimated.

7.4.4 Supporting Evidence

Supporting evidence or outward symptoms of "quality", as demonstrated by such things as documentation detail, should be used as a criterion to weight both historical costs and expert opinions. For instance, one objective (non-personal) measure of "quality" is the currency of the input. Thus, by and large, a later historical report on a given area of cost will normally take precedence over an earlier report. Or, if the same expert or two experts of equal competence estimate at six-month intervals a given cost, the latest estimate will normally be rated more heavily.

In considering the credence or weight to be attached to historical data, such considerations as sample size, representativeness, and consistency of relationship should be evaluated. In other words, historical data are frequently samples rather than a complete tally.[5] In such cases it is pertinent to inquire as to how many observations were in the sample and how typical or representative of the universe or population was the sample. If the historical experience is expressed as a single value, it is pertinent to inquire as to how consistent a relationship, how much dispersion within the observed range, do the raw data reveal.

In evaluating projected data, it is most important to avoid undue glibness relative to expert opinion. In this case, as with historical data, it is well to look for objective evidence of careful research, qualitative and quantitative, to support the opinion. Each expert should also be carefully assessed on such bases as his reputation, the effort applied in reaching the particular opinion, and what might be called his "consensus rating". Thus, by virtue of their past successes and failures in estimating future trends and costs, some experts have developed greater reputations than others, and thus should be weighted more heavily. However, reputation is not a sole and sufficient criterion, and it is desirable to differentiate among even acknowledged experts for the relative time and effort they spent in making a particular estimate. Even the most experienced authorities have been known to make purely intuitive guesses when pressed to do so or when time is short. Failing all else, there is some safety in numbers. A consensus of expert opinions is normally better than one, and especially when projecting advanced developments, one way of evaluating an individual expert's opinion is the extent to which it is shared by his colleagues.[6]

The above criteria are merely indicative of the type of weighting criteria that might be developed to convert cost data inputs into cost data outputs (system element costs). As indicated previously, extremely little formal methodological research has been done on this very important step in estimating the costs of a military system. Like in the other military applications of weighting methodology alluded to in Section 7.2.2, further research in the realm of cost-data-input weighting criteria should be directed toward finding increasingly more explicit and reproducible, preferably quantitative measures of what are essentially qualitative phenomena.

7.5 The Problem of Uncertainty

7.5.1 Nature of Problem

One of the most baffling problems that frequently confronts a cost analyst is how to make his cost estimates reflect the tremendous uncertainties that often underlie his findings.[7]

Although the relative importance of minimizing uncertainty in the cost estimate varies with the client's intended application of the estimate (Chapter 2), it is always desirable, whatever the type of estimate, to reduce uncertainty. The importance of uncertainty lies in the implication it has for the client if the cost estimates he receives are seriously in error. Since comparative costs are properly regarded as one of the appropriate criteria in choosing among system alternatives, a seriously erroneous cost estimate can lead to seriously wrong choices among system alternatives with the result of gross misallocations of resources among different programs.

7.5.2 Historical Record

In approaching the subject of uncertainty as it applies to system cost estimating it is useful to examine the historical record concerning the relative accuracy of system cost estimates in the past. In some cases data are too sparse to make a comprehensive examination; for instance, large military electronics systems and space systems are too recent a development to make definitive post-mortems of advanced systems cost estimates completed to date. As far as the writer knows, no one has, to date, examined systematically the limited data that are available in these fields.

As mentioned in Chapter 2, RAND has made a series of empirical studies covering aircraft and missile systems. The major findings of these studies have been as follows:

a. Many advanced system cost estimates have seriously erred.

b. Most of these errors have been underestimates rather than overestimates.

c. There has been quite a range in error from system to system. One of the consequences of this wide range is that it is not practical to avoid serious errors in future cost estimates merely by adding a standard "fudge factor" to all first-pass cost estimates.

d. To the extent that the reasons for past errors can be traced or inferred, "requirements uncertainty" far out ranks in importance "cost estimating uncertainty". In other words, most costing errors have been due to the fact that the system configuration changed substantially as the system progressed from initial concept through operating capability, not the fact that the cost analyst wrongly priced the resources of the initial configuration. As an illustration, if a serious error in the total system cost could be traced to a major error in personnel costs it would normally be attributable to the fact that the cost analyst was proceeding from seriously mistaken information relative to the types and numbers of personnel required rather than the fact that he incorrectly costed an airman at $3,000 per year rather than at $4,500.

e. Additional RAND studies[8] have shown that cost uncertainties and probable errors in system costs are highly correlated with:

(1) the stage of the system's development during which the cost estimate is made. The earlier in the system's development cycle that the estimate is made, the greater are the chances of a serious costing error.

(2) the length of the system's development period. Systems with long development periods are more susceptible to serious costing errors than are systems with short development periods.

(3) the degree of technological advance required. The greater is the amount of technological advance required to satisfy

the system's requirements, the greater are the chances of a serious costing error.

However, as a practical matter it is generally hard to measure any of these parameters at all precisely and, therefore, it is hard to use these findings to guesstimate how much uncertainty exists and how much relative inaccuracy is likely to characterize any given cost estimate.

7.5.3 Four Objectives

The cost analyst and his client are interested in doing four things about uncertainty:

a. A basic objective guiding practically everything the cost analyst does on a costing project is to reduce the uncertainty surrounding his findings. He strives to end up at the conclusion of his study with a residual, hard-core uncertainty.

b. After he has done everything possible to minimize uncertainty, the analyst wants to be in a position where he can assess both the nature and magnitude of the remaining uncertainty with reasonable confidence. Actually, of course, he attacks this "nature and magnitude" problem from the beginning of the study (Chapter 2), because he cannot proceed systematically to reduce uncertainty until he knows wherein it lies. The "nature" of uncertainty refers here to such considerations as whether the major uncertainty is "configuration uncertainty", as defined above, or "cost estimating uncertainty"; also, it is concerned with identifying which particular cost elements are characterized by the greatest uncertainty.

c. After he has clarified in his own mind the nature and magnitude of the residual uncertainty, the analyst wants to convey to his client as meaningfully as he can his (the analyst's) knowledge and feelings relative to this uncertainty.

d. Finally, it is a joint responsibility of the cost analyst, the cost methodologist and the client to determine as specifically as possible how this information concerning uncertainty can be <u>used</u> to make better cost/effectiveness type decisions in system selections than single-value estimates can provide.

7.5.4 <u>Reducing Uncertainty</u>

Since there is a close, inextricable connection between uncertainty and the accuracy of cost estimates all system cost methodology, including the total content of this document, is addressed by implication toward helping the cost analyst reduce uncertainty. For instance, the emphasis placed in Chapter 3 on the analyst making the description of the system to be costed an early and continuing responsibility reflects the fact that historically most wrong cost estimates can be traced to the difficulties (uncertainties) associated with correctly describing the system to be costed.

7.5.5 <u>Assessing Uncertainty</u>

As indicated in 7.5.3 above, the task of pinpointing the nature and magnitude of uncertainty is a continuing task that the analyst faces from the beginning to the end of a study. If he has systematically attacked his first task, namely, reducing uncertainty, he will have progressed toward assessing uncertainty even if he has not been successful in actually reducing this uncertainty. In other words, he should have a fair understanding as to what, specifically, he is uncertain about.

At this point, however, a word of caution is required. In practice, these element-by-element uncertainty assessments are likely to be highly personalized in terms of the temperament or even the temporary mood of the analyst. Thus, two different analysts when confronted with the same set of data inputs are liable to arrive at vastly different uncertainty assessments, and even the same analyst, depending upon his temporary mood, may arrive at much different uncertainty assessments. The almost inherent capriciousness of this undertaking is a major obstacle toward systematizing the process of cost estimating. To the extent that this capriciousness is not dealt with, the uncertainty assessments may do as much harm as good, especially if the analyst and client both place any substantial confidence in these assessments.

There is really only one way, known to the writer, of reducing capriciousness and intuition in this area. This is to aim for greater explicitness and replicability in deriving and documenting the rationale supporting uncertainty assessments. The basic characteristics and illustrative examples of this explicitness for single value estimates were outlined earlier in this chapter. Elements of this explicitness were contained in the RAND "Delphi" experiments cited on page 117 of this chapter. Operationally what it means is that the cost analyst should strive to support both logically and empirically the judgments that he reaches relative to his uncertainty assessments. The value of this exercise, as explained previously, is that it facilitates a check for reasonableness and consistency both immediately by the cost analyst, himself, and by his colleagues on the project, and also improves the chances of long-term learning from subsequent feedback information.

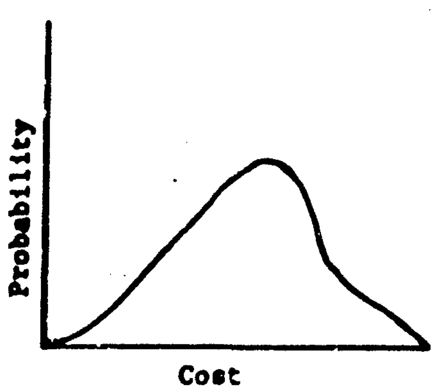
But there is still another problem. Usually, the analyst's knowledge or feelings relative to uncertainty will be particularized by elements since, as noted previously, most systems are costed in terms of their constituent elements. A remaining task is to translate and consolidate these separate element uncertainties into an integrated expression of the uncertainty in the total system cost estimate. Even if the analyst has succeeded in quantifying his uncertainties on an element by element basis into a range of costs for each element, it is not legitimate to derive an assessment of uncertainty in the total system cost estimate merely by a straight addition of the ranges for the individual elements.

Potentially, this consolidation of individual element uncertainties into an integrated uncertainty assessment for the total cost estimate provides another field-day opportunity for subjective, intuitive estimating. Fortunately, however, it is not necessary to resort to intuition to make this integration, provided it is possible to quantify the individual element uncertainties into a probability distribution. If it is possible to so quantify the individual element uncertainties, techniques have been developed which make it possible to calculate in a completely explicit, reproducible (non-personnal) fashion a quantitative estimate of the uncertainty in the total system cost estimate.[9]

..5.6 Expressing Uncertainty

Restating the third task, after the analyst has clarified in his own mind, the nature and magnitude of the residual uncertainty, he wants to find a means of conveying this knowledge to his client as meaningfully as he can.

There are various means the analyst can employ to convey his knowledge relative to uncertainty. Most of them involve probabilistic statements and they are mainly differentiated by their degree of specificity. This differentiation may be illustrated by the following hypothetical example, beginning with the single value estimate with no uncertainty assessment.

EXPRESSION FORM	DEGREE OF SPECIFICITY
1. System A is estimated to cost $15M.	1. No uncertainty expression.
2. System A is estimated to cost $15M; however, the analyst is not sure (uncertain) about the figure.	2. A vague qualitative expression of uncertainty is given.
3. System A is estimated to cost between $11M and $19M.	3. A range is given to express the magnitude of uncertainty. However, no probability information is given; it is not stated whether the analyst believes there is a 1%, a 10% or a 100% chance that the cost will fall between $11M and $19M, nor is it indicated whether the cost is likely to be closer to $11M or $19M.
4. There is a "strong probability" that System A's cost will be: $11M - $15M - $19M. The $15M is some measure of central tendency (mean, mode or mean). The $11M and $19M are the estimated lower and upper cost limits.	4. An adjective descriptor is added to convey a rough indication of probability.
5. With a .95 probability, System A's cost is estimated: $11M - $15M - $19M. The numerical expressions have the same meaning as in 4 above.	5. The adjective descriptor is replaced by the more definitive numeral.
6. 	6. A complete probability distribution is given, and this is depicted by a curve. (Both the problems in getting the Case 6 type information and the amount of additional information provided by Case 6 are of a greater magnitude vs Case 5 than Case 5 is vs Case 4, Case 4 is vs Case 3, etc.)

The above examples are provided merely to illustrate some of the types of uncertainty expressions that might be employed. Many variants of the above types plus other basic types might also be used. For instance, a minor variant of Example 3 above would include a measure of central tendency as well as the two outer limits. Another method would be to express the range in standard deviation units measured from some measure of central tendency. Other measures -- short of a complete frequency distribution -- would depict the relativeness skewness or "peakedness" (kurtosis) of the distribution; also a "tail probability" could be used to indicate the upper or lower limits of the distribution. The preferred measure in any given study would depend upon the type of information available to the analyst, the client's intended use of the estimate, and the client's relative familiarity with statistical methods.

7.5.7 Using Uncertainty Assessments

In the past, system cost methodologists have seldom specified how probabilistic cost estimates or other uncertainty assessments could be used to make better system choice decisions than could single value estimates. (Raiffa and Schlaiffer have, however, treated similar problems in a more general context.)[10] By the same token, decision makers frequently have an inherent bias against probabilistic answers. The decision maker, himself, normally has to make single-value type system proposals to his superiors, e.g., requests to Congress for funding must be for a specified number of dollars. Moreover, even in planning type problems, probabilistic cost estimates usually complicate the decision, they never simplify it. For instance, in the following example it is assumed that alternative systems A and B offer equivalent effectiveness for meeting a specified requirement.

System	Single Value Estimate	Probabilistic Estimate (95% range)
A	\$15M	\$12 - 15 - 18
B	\$13M	\$10 - 13 - 20

Whereas the single value estimate clearly suggests System B, the probabilistic estimate offers no clear mandate.

Notwithstanding its tendency to complicate the decision problem, probabilistic estimates offer both tangible and intangible advantages over single value estimates. In the first place, the additional information provided by a probability estimate may cause a decision maker to make a different, and what he regards as a sounder and safer, decision than a single value estimate would. This is likely to be true, for instance, when a decision maker has a upper limit cost threshold. In the following illustration it is postulated Systems A and B offer equal effectiveness and that under no circumstances does the decision maker want to spend more than \$18M on the proposed system.

Cost in M\$	Probabilities	
	System A	System B
under 12.1	0.3	0.3
12.1 - 15.0	0.4	0.3
15.1 - 18.0	0.3	0.3
18.1 + over	0	0.1
Single Value Cost	\$15M	\$14M

In view of the upper limit cost threshold constraint, System A may be a preferred choice over B. This insight would be forthcoming from the probabilistic cost estimate; it would not be revealed by the single value estimate.

Second, even when a decision maker must furnish to his superiors a single value cost estimate, a probabilistic cost estimate can be a very useful input to him, especially if the distribution is upwardly skewed, in suggesting that provision be made for either an explicit or implicit allowance for contingencies. While the probabilistic estimates can be a useful input to the decision maker in establishing his contingency allowance, there is no way to establish the amount of this allowance apart from the client's loss structure (Loss structure is defined here as the utility or disutility a client assigns to various types, magnitudes, and timings of possible cost outcomes or expenditures) If the client puts a very high premium on not running short of funds, if he does not want to risk a program's chances of a sound development for want of funds, he will set a high contingency allowance. On the other hand, he may also feel that if he establishes the contingency allowance at a very high figure, the total system cost may be so high that DOD may disapprove the program. Only he can balance the two and resolve the issue.

Third, probabilistic cost estimates generated as an input to a planning type decision may on occasion suggest to the decision maker that he really does not have sufficient information to make a choice among his existing alternatives In other words, the probabilistic estimates may suggest that the uncertainties are so great and the choice among the alternatives so inconclusive that the best decision would be to buy more information, to do additional research to clear up some of the uncertainties relative to existing alternatives or to uncover or create new alternatives that would be superior on a cost/effectiveness basis to any existing alternatives. Again, the simpler answers provided by the single value estimates would mislead the decision maker The following example illustrates this point.

To highlight the issue it has been assumed that effectiveness as well as cost is subject to uncertainty, a not at all unrealistic premise.

System	Single Value Estimates		Probabilistic Estimates (95% range)	
	Effectiveness	Cost	Effectiveness	Cost
A	100	$15M	70 - 100 - 110	$13M - 15M - 20M
B	90	$17M	75 - 90 - 120	$13M - 17M - 21M

(Raiffa and Schlaiffer have devised a method for guiding the decision maker under certain circumstances to decide how much money it is worth spending to buy additional information, provided the client can spell out in sufficient detail his loss structure (how much specific types of information would be worth to him, etc.) and his cost distribution.)

Fourth, probabilistic cost estimates are valuable in that they prod decision makers to think more thoroughly about the full implications of the decisions they have to make. For instance, the range of possibilities posed by the probabilistic type data exhibited in the table above is much more likely to lead a decision maker to examine and formulate the details of his loss structure than is a single value estimate. Finally, having been alerted to the specific uncertainties underlying the data on which he must make his decision, the military planner is much more likely to make flexible type decisions, is much less likely to be "caught flat-footed" if subsequent experience disproves the most likely estimate, and to be ready with alternative, contingent plans that will minimize his realignment losses.

Another means available to the analyst of attacking the uncertainty problem and of communicating the resource implications of this uncertainty to his client is through cost sensitivity studies. Through these studies a cost analyst can inform his client what is likely to be the impact on total system costs (the range of costs) from varying key systems performance or design parameters through a specified set of alternatives. This type of information will, for instance, tell a client how much, at worst, he may be hurt by the residual uncertainty in his system, and it can help him decide whether to buy more information, to retain the status quo, etc.

7.6 Computerized Cost Models

7.6 1 Definitions

A number of computerized cost models have been developed to facilitate the process of estimating a system's costs. No attempt will be made in this document to review in any detail the characteristics of these models since a mere description of any one of them would take many pages. However, it is pertinent to highlight some of the major advantages and limitations of such models, and to discuss the conditions under which they are likely to be most useful.

Practically all system cost estimating models consist of a series of statistical equations or cost estimating relationships which relate various types of costs to each other and various types of costs to selected performance or design parameters When the estimating process is computerized, the computer model is used to convert these various input relationships into an output, a system cost estimate

In this paper the discussion will focus on a computer cost model developed by MITRE to cost electronic systems. However, many of the advantages and limitations of this model also are characteristic of other types of cost models. A detailed description of the MITRE cost model is contained in the paper by T. Jannsen, H. Glazer, and J. DesRoches referenced in Chapter 4 (page 71, footnote 2). This model, when furnished with the necessary input data, including a description of the system in terms of its elements, the statistical (cost) relationships between these elements, and a description of the output tables desired, will automatically calculate and print the desired cost estimates. Many of the required inputs are routinely stored within the model and the analyst selects the appropriate ones or inserts new ones into the model when he wishes to make an estimate.

7.6.2 Explicitness

Because a computer can only accept expressly defined and quantitively stated inputs, the decision to use a cost model automatically imposes on the analyst a requirement to be more explicit and systematic in working out and documenting his cost estimating methodology than might be the case if the mechanics of his estimating procedure were purely manual. In this sense a cost model contributes to a realization of the advantages of systematic analysis expounded in this paper.

However, this point should not be pushed too far. Although the use of a model requires an explicit statement of the various inputs used, a computerized procedure, no more than a manual procedure, can insure that these inputs are derived in an explicit, replicable fashion. Historically, much of the most damaging implicitness of manual costing procedures arise in connection with the derivation of the estimating relationships, and no computer model, per se, can correct this condition.

7.6.3 Time Saving

It is in the realm of saving time in calculating and printing the cost findings that potentially a computerized cost model offers its greatest potential advantage. To the extent that it does so, a computerized model can make it possible for the estimating staff to spend relatively more time in analyzing the cost results as opposed to routine processes of calculating and printing such results. This advantage is likely to be most evident, of course, when the arithmetic calculation work is very large. Most notably this is the case in cost sensitivity studies for orienting the system design in advanced planning projects. In such cases a computerized model makes it possible to proceed quickly through many cost iterations to ascertain the impact on total system cost of varying the values of selected system performance or design parameters Similar advantages accrue in force structure analysis when it becomes necessary to make an element-by-element estimate concurrently of several hundred different systems.

Two cautions should be noted, however, in this connection. First, a certain amount of set-up time is usually required to computerize the estimating procedure of a particular problem. Unless the total calculation workload is substantial, the total time required to process an estimate through a computerized model may be as great or greater than for a manual costing operation in which a desk calculator is used for the arithmetic operations. In practice, very many system cost projects require a relatively small calculating workload in which the estimating relationships used are very simple linear factors. In such cases a computerized cost model will not save time in calculating a system's cost.

Second, when a computerized procedure does save time, it is mostly in the realm of relatively routine tasks -- arithmetic calculation, printing, and reproduction. Most of the existing computerized cost models usually do not save time in areas where an analyst spends most of his time -- defining the requirement and configuration to be costed, collecting and evaluating his cost inputs, and writing and interpreting his narrative report.

7.6.4 Presentation

Chapter 9 will discuss in some detail the importance of proper presentation of the cost findings to the client and the problems in doing so. It is relevant here, however, to comment briefly on the suitability of the computer printout as a presentation format. In some quarters the high respect accorded generally to the computer as a powerful research tool may generate in the mind of the client a high-order confidence, sometimes unwarranted, for the cost findings, themselves. On the other hand, some clients find it more difficult to follow the computer printouts than a simple, typewritten page. When this is the case, the computer presentation may hinder the analyst in effectively communicating his findings to his client.

In summary, a computerized cost model, like other cost analysis tools (standardized cost structures, generalized cost estimating relationships, and techniques to assess and express uncertainty), can be a powerful research tool if used with discrimination. It is not, however, a general purpose tool suitable for all occasions.

7.7 Summary

This chapter has been concerned with the mechanics of converting cost data inputs into cost element estimates. It has been noted that the complexity of this operation is a function primarily of the number, diversity, validity, and relevance of the data inputs to the new element being costed.

Whenever the analyst has two or more data inputs relating to a cost element, he must weight these inputs in reaching his estimate of the cost of the new element. If this weighting is to be done objectively, rather than subjectively, two methodological steps must be taken. One, relatively explicit, measureable criteria must be established for accomplishing this weighting. Second, a format must be established for combining and displaying or documenting the weighting determinations. Illustrative criteria and formats have been discussed in this chapter.

The problem of handling uncertainty is one of the most difficult confronting the cost analyst. There are four facets of this problem: how to reduce uncertainty, how to assess its nature and magnitude, how the analyst can meaningfully communicate his findings relative to uncertainty to his client, and how the client can use these uncertainty assessments to make better cost/effectiveness decisions than can single value estimates.

A computer cost model will save substantial time and offer other related advantages when the arithmetic workload in calculating a system's cost is substantial such as in cost sensitivity studies and force structure analysis.

FOOTNOTES

Page

[1] Illustrative of the literature on this subject see: C. G. Hitch and R. McKean, Economics of Defense in the Nuclear Age, Harvard University Press, 1960, Chapter 9; R. G. Davis, Preference Structures and the Measurement of Military Worth, Princeton University Press, 1960; W. V. Caldwell, M. S. Schaeffler, R. M. Thrall, C. H. Coombs, "A Model for Evaluating the Output of Intelligence Systems," Naval Research Logistics Quarterly, March 1961, pp. 25-40; J. A. Evans, "Planning Effectiveness Criteria and Trade-Offs Associated With The USSTRICOM Augmentation Mission," (Project 603.0), The MITRE Corporation, WP-6817, February 1964. — 108

[2] This search for objective, explicit weighting schemes has been particularly prevelant in the procurement of electronic computers. For instance, see the papers by Ed Joslin ("Cost-Value Technique for Evaluation of Computer System Proposals"), and Sol Rosenthal ("Analytical Technique for Automatic Data Processing Equipment Acquisition") delivered at Eastern Joint Computer Conference (Washington, D. C., 21-23 April 1964). Also: J. A. Campise, "A Quantitative Approach to Equipment Comparison," Journal of Data Management (October 1963) and Space Technology Laboratories (Controller's Department) Computer's Evaluation Technique (July 1960). E. I. Friedland, "How To Select the Best Computer," The MITRE Corporation, W-6231 (1 July 1963). One of the best and latest papers is by J. R. Miller and C. F. Wolfe, "Making Cost/Effectiveness Trade-Offs in EDP System Selection," The MITRE Corporation, TM-4032 (26 June 1964). — 109

[3] For a discussion of this program see: National Defense Education Institute (Harbridge House, Inc.), Guide for Incentive Contracting, 1962. A concise summary of the program's objective appeared in: Missiles and Rockets, 16 September 1963, pp. 8-10. — 110

[4] Logistics Management Institute, Study of Profit or Fee Policy, (Project 5B1: DOD Contract SD-110-16).

[5] USAF, Planning Factors Manual (PFF) - AFM 172-3. — 116

[6] RAND has conducted an interesting experiment that aimed to provide a systematic, explicit approach to eliciting a consensus of expert opinions relative to a military system analysis problem. Norman Dalkey and Olaf Helmer, "An Experimental Application of the Delphi Method to the Use of Experiments," RAND RM-727-PR (Abridged) July 1962. — 117

FOOTNOTES (Cont'd) **Page**

[7]Although literally dozens -- perhaps hundreds -- of articles on uncertainty have appeared in the learned journals, very few of them have much practical relevance to system cost analysis. Once again in this instance the RAND literature is the most directly relevant, e.g., Hitch and McKean, op. cit, pp. 188-205, and G. H. Fisher, "A Discussion of Uncertainty in Cost Analysis (A Lecture for the AFSC Cost Analysis Course)," RAND RM-3071PR, April 1962. Also relevant in a general sense are the writings of Haward Raiffa and Robert Schlaiffer, e.g., Applied Statistical Decision Theory (Harvard University, 1961). 117

[8]E. g., Robert Summers, "Cost Estimates as Predictors of Actual Weapon Costs: A Study of Major Hardware Articles," RAND RM-3061PR, April 1962. 119

[9]Sobel, op. cit. 123

[10]Op. Cit. 125

CHAPTER 8

ESTIMATING CERTAIN HARD-TO-MEASURE COSTS

8.1 The Conceptual Issue

The preceding several chapters have been concerned essentially with how best to measure the generally recognized direct mission cost elements of a system. Illustrative of such cost elements would be the purchase cost of an electronic computer to serve as a major mission element of a system, the costs associated with hiring a private contractor to initially write and periodically up-date the computer program essential to the use of this computer, and the construction of a new building in which to house this computer. No one questions that any of these costs are legitimate costs of the hypothetical system. Methodological or procedural questions are concerned principally with the most accurate and expeditious means of estimating these costs 3 to 10 years before the system becomes operational.

In this chapter the discussion returns to a question alluded to in Chapter 2, namely, how should cost be defined, i.e., what types of cost should be included or excluded from the definition? The issue probably can be epitomized in a distinction between the two basic concepts of cost discussed in Chapter 2, namely, the distinction between a cash-flow concept appropriate for funding type decisions and a value-flow concept appropriate for planning (choice-among-alternatives) type decisions. The value-flow concept contends that in order to obtain a complete and true measure of the total resource impact of a system alternative, it is frequently necessary to include as important costs certain elements not reflected in the flow of funds required to develop, acquire, and operate a system.

Conceptually, some of these costs are akin to what economists have termed "external economies and diseconomies." Hitch and McKean, borrowing a term from J. M. Buchanan, call these costs "spillovers."[1] Some of these costs also derive from the economist's notion of an opportunity cost in the sense that a decision to use a scarce, valuable, multi-purpose resource in one way precludes its use in other alternative, productive employments. Accountants might label some of these costs as imputed costs in the sense that some activities of System A indirectly have resource-oriented implications or reactions on another System B without directly and necessarily causing a change in the funding to System B.

The main concern of the present chapter will be to discuss the problems involved in identifying some of these value-flow type costs and in measuring them once identified.

8.2 Hard-To-Measure Costs

8.2.1 Inherited Assets

A new system frequently "inherits" some of the resources required for its development and operation from other systems previously or currently deemphasized or phased out of the military force.

A cost estimate prepared for funding purposes will not include a charge for inherited assets, *per se*, because the assets were paid for by the previous user. In other words, no new funding is involved, except perhaps to repair, modify or transport the asset to the new user.

However, if the objective is to prepare an estimate of the total real cost impact of a system and to use this cost estimate as one criterion in evaluating the subject system competitively against other systems as a means of accomplishing a given mission or of enhancing the nation's military posture most cost methodologists would agree that under certain conditions the cost estimate should include some charge for inherited assets.

The rationale for this principle is an outgrowth of the neo-classical economics concept of "opportunity costs" and has been recommended by many authorities as applicable in civilian costing as well as military.[2] In effect the principle states that the true cost of a resource used in one employment is represented by the foregone opportunities of using that resource elsewhere. Hitch and McKean in discussing its application to military systems costing have coined the term "alternative use" principle.[3] The conceptual and empirical ramifications of this doctrine will be discussed later.

8.2.2 Shared Assets

A new system may not require the full and exclusive use of all of the resources contributing to its effectiveness. In other words, a system will normally share with other systems the services of certain mission-type or support assets. An example of shared mission-oriented assets would be communication lines functioning as subsystems of two or more systems. On the other hand, support type assets or services can be at either high or low echelons of authority. For Air Force systems examples of high-level support services are those provided by Headquarters USAF, AFSC, AFLC, ATC, the Air University, and the Office of Aerospace Research. Examples of low echelon support activities on the post, camp or station level are the mail service, dispensary, and commissary.

Once again, a funding estimate prepared in support of a given system frequently will not include a charge for such services because the total funding requirements for such activities are financed on a consolidated basis through other echelons.

However, resources consumed in providing such joint services are in principle as much a drain on the Defense budget and on the gross national product as are those directed to meeting the exclusive requirements of a system. Again for the purpose of estimating the total cost impact of a new system in order to evaluate it on a cost/effectiveness basis against other systems, there is no rational reason for ignoring such costs. There are, however, real practical problems in identifying and measuring these costs in a system context and they will be considered later.

8.2.3 <u>Fixed Supply Assets</u>

The level of Defense Department expenditures for certain very important classes of resources are comparatively insensitive to the requirements of a particular system for these resources. For instance, Congress decides on the total size of the military force and on the respective strengths of each Service (Army Navy, and Air Force) substantially independently of the anticipated needs of particular "systems" or "program elements" for military personnel. Thus, in recent years for diverse and complex reasons Congress has set the size of the total Armed Forces at approximately 2.500,000 military personnel and the Air Force at 800.000 - 900,000 military personnel. The particular strengths authorized were substantially uninfluenced by whether electronic system XYZ anticipated a need for 1,000 men or 5,000 men.

Similarly, in terms of budget procedures, military personnel expenditures are funded on a consolidated basis and the funding estimate prepared on the lower echelon system level normally does not include military personnel costs. However, higher echelons of the Air Force and the Department of Defense try to allow for such costs in evaluating alternative system proposals. Headquarters USAF, for instance, adds military personnel costs to the PSPP (Proposed System Package Programs) before submitting the programs to DOD for approval.

Again, as in the case of support costs, if the cost estimate is intended as an input to a planning type decision, it is appropriate to take account of the comparative military personnel requirements of the several alternative systems. However, there are practical problems in doing so, and these, too, will be discussed later.

8.2.4 Salvage Values

A rationally (economically) motivated private consumer does not ignore the potential eventual trade-in value of an automobile when he estimates what will be the real, net costs to him of owning an automobile or in making a choice among different automobiles.

Similarly, in estimating the real costs of his alternative systems, a rationally (economically) motivated military decision maker should not ignore the differences in potential salvage values that his various system alternatives may offer when they are eventually discontinued.

For instance, if System A costs $50,000,000 and has anticipated salvage values to successor systems of $10,000,000, its net cost is $40,000,000. On the other hand, if System B costs $60,000,000 and has anticipated salvage values to successor systems of $25,000,000, its net cost is $35,000,000. In effect, the real resource drain of System B is less than A even though its initial gross costs are greater.

The foregoing type considerations are not germane when calculating the short-term funding requirements of a particular system. They are, however, pertinent when the objective is to make optimum use of the Department of Defense total resources in a long-term context. The difficulties of implementing this guidance will be discussed later.

8.2.5 Spillovers

A leading characteristic of large military systems is the close functional inter-mesh and great operational interdependency among such systems. In costing a system for planning purposes - when the objective is to estimate the total real net costs of a system - the cost analyst should be alert to the possibility that the introduction of a new system can indirectly give rise to either increases or decreases in the costs of other, related systems. Once again from the point of view of extracting the most mileage from the defense dollar with the objective of securing the strongest possible total military posture, these spillovers should be considered in evaluating system alternatives.

Illustrative of the spillover phenomenon, in one MITRE cost study it was found that a contemplated, new command and control system would make it possible to eliminate the survivability requirement, and hence to reduce the costs, of a previously approved major system.

8.3 Data Problems

There are many important and difficult empirical problems associated with estimating the system non-funding type costs discussed in Section 8.2.

8.3.1 The Magnitude Issue

There is, first, a need for much fuller information concerning the relative quantitative significance of system non-funding type costs to t e total military decision problem. It is important to know this information because the potential error in the total system cost estimate that an improper handling of these costs can cause depends to a large extent on the relative percentage that these costs represent of total system costs.

a. Inherited assets and salvage values are a case in point. It is known that the Department of Defense holds title to truly tremendous assets; Secretary of Defense, Robert McNamara, has estimated the value of these assets at $200,000,000,000. It is also general knowledge that periodically old systems are retired, new ones introduced, and existing systems modified, with the life of the average system probably under ten years. In this dynamic situation there is certainly some transfer of assets from one system to another. On the other hand, it is certain that some, maybe many of these system assets consist of highly specialized equipment with a zero or very low alternative use value. This writer, however, has been unable to learn how much transfer of assets in the aggregate from one system to another actually occurs.*

b. It would also be useful to have a "ball park" order-of-magnitude estimate on the relative percentage of the total Defense budget that could be ascribed as direct mission costs, low level support, intermediate level support, and high level support.[4] These figures would give a general clue concerning the relative importance of accurately estimating the support costs of alternative systems.

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*Specific cases can be cited, however. For instance, $45,000,000 (original cost) of radar and related equipment released by the Army's Nike-Ajax system was distributed among a host of different agencies:

Air Force Missile Center, Cape Canaveral
Naval Ordnance Test Station, China Lake, California
Naval Air Test Center, Patuxent River, Maryland
Naval Research Laboratory, Washington
Air Defense Engineering Agency, Fort Meade, Maryland
NASA, Langley Field, Virginia
NASA, Wallops Island, Virginia

c. The importance of the military personnel component of the "fixed supply" type of asset is fairly well established in the broad aggregate; roughly 25% of the $50,000,000,000 Defense Budget is for military personnel costs.

8.3.2 Lack of Integrated Records

As far as the writer knows, there is at the present time no comprehensive, centralized program - official or unofficial - for collecting much of the specific types of information needed for estimating the system-non-funding costs identified in Section 8.2. There is, for instance, no centralized program within the Department of Defense that summarizes what inherited assets are potentially available to a proposed new system, that identifies the major potential competing systems that could use given assets, and estimates the "alternative use" value of these assets to each of the potential users.

8.3.3 Dissemination Problem

There are also practical, administrative problems connected with disseminating this non-funding type of information - if it were available - to the personnel responsible for initially generating system cost estimates. The alternative-use costs, high level support costs, spillover costs, and other non-funding costs described in this chapter are what economists call "macro-economic" data; they imply an intimate knowledge of the total military force structure, not only current but projected. System cost estimates, on the other hand, are initially prepared on a "micro" or relatively low echelon level. The micro analysts normally have a rather fragmentized knowledge of the macro state of affairs, and it would take some major realignment in such considerations as "privileged information" and "need to know" to make this macro-type information available to the micro analysts, even assuming that higher echelons were to collect and consolidate it in a form that would be useful as inputs to the individual system cost study.

8.3.4 <u>The Meaningful Data Problem</u>

Answers to many of the cost questions raised in this chapter are inherently elusive, so that the problems even in the long run of obtaining meaningful data are great:

8.3.4.1 <u>Delayed, Oblique Costs</u>. The cost impacts referenced in this chapter are often delayed and oblique, and accordingly, very hard to measure. For instance, salvage values estimates must be projected 5 to 15 years into the future and inevitably are enmeshed in great uncertainties relative to the nature of the requirements of the successor system. Additionally, in a strict sense, salvage values should be "discounted" to present value before incorporating them into a system cost estimate. However, the practical problems involved in selecting defensible, empirical-oriented discount rates are formidable.

Similarly, support cost impacts, especially high level support, are oblique, and are filtered through several or many administrative echelons. Contrast the difficulties in measuring these types of cost with the relatively immediate and straightforward costing of the construction of a direct mission building, the purchase of a certain piece of mission equipment, or the hiring of direct operating civilian personnel for a particular system.

8.3.4.2 <u>Biased Costs</u>. Another data complication is that the major potential data sources for the required information are both highly subjective and inevitably biased. For instance, in estimating the alternative use value of an inherited asset, it would certainly be necessary to obtain, or at least check, such values with the potential users of the assets. However, a potential user is likely to formulate his "official" estimate of the value of an inherited asset to him in terms of his political strategy for winning custody of the asset in competition with other potential users.

Similarly, in estimating the resource impact of a new system on certain fixed supply or shared assets, it would seem logical to request the agency providing the service for a statement of its ability to absorb additional workload without a commensurate increase in staffing. However, it would be naive to expect an unbiased answer from such agencies.

8.3.4.3 Hypothetical Costs. Apart from the matter of bias, many of the cost impact questions raised in this chapter are basically hypothetical or conjectural, rather than strictly empirical. For instance, the "idle capacity" question raised in the case of fixed supply or shared assets, provides a "field day" opportunity for speculation as to what would be the level of utilization of the service and the quality of service rendered to other users if the new system were not introduced. The question is such that even an entirely unbiased observer would have difficulty in formulating impersonal answers.

8.4 General Ground Rules

8.4.1 Premise

The very serious data problems, referenced above, markedly limit the ability of an analyst to provide in a planning type estimate for the system non-funding type costs discussed in this chapter. However, in this connection a statement by Charles E. Hitch is relevant. In discussing why it is important to estimate the total, rather than the partial, cost impact of a system he said:

> While the accuracy with which we can predict such costs may leave something to be desired, it is clear that at least trying to take such factors into account is preferable to ignoring them.[5]

Although the problems of identification and measurement are difficult, they are not hopeless, and certain guidance, both general and specific, can be suggested as a start toward a set of principles for systematically handling these costs in a planning type study. The general guidance will be reviewed first.

8.4.2 Identification

An analyst responsible for making a planning-decision cost estimate should be acutely alert to the following: one, there are many ways in which "real" costs can be generated that differ fundamentally from those included in a funding estimate. Two, the relevance of a particular type of cost to a system decision and the desirability of taking that cost into positive consideration is not necessarily associated with the ease of measuring that cost. Accordingly, the cost analyst in estimating a system's cost should not ignore or assume away whole areas of costs merely because they are hard to measure.

If the analyst discovers or suspects certain hard-to-measure, potentially significant, oblique, indirect areas of cost in the process of his study, he should include them in his report to his client. If he cannot quantify such costs, he should make a descriptive note of them. His client or a higher echelon office, if alerted to them, may be able to quantify them.

Even if these indirect costs cannot be quantified, a knowledge of their existence may still be important. Thus, if two system alternatives, A and B, offer equivalent total effectiveness and equivalent monetary, funded costs, but B involves substantial, indirect, non-funding costs and A does not, A would be preferred.

8.4.3 Incremental Cost Concept

It will be recalled that in Chapter 2 the point was made that in a planning type estimate it is appropriate to omit certain cost elements when the omission has a neutral cost impact on the comparative costs of the system alternatives under consideration and on the decision to be made. Thus, if two system alternatives would involve identical research and development costs, it is legitimate to omit the research and development costs from the analysis, and to make the decision solely in terms of the comparative investment and operating costs.

This way of looking at the analysis problem has been generalized into what has been termed the incremental cost concept[6], and it provides a useful operating criterion in deriving planning type costing estimates. In effect, this concept states that a planning type estimate should include only the incremental costs of a system decision, the costs specifically generated by the system decision and which could be avoided if it were decided to forego that system decision. This concept stresses the principal of "total cost impact" rather than total costs, *per se*.

Sometimes incremental costs are simply defined as future costs. Strictly speaking, this is incorrect. An incremental analysis can be made in which the previously defined system capability is an already approved level of future capability. In this situation the costs to cover this previously defined system capability would not be incremental costs. For instance, the Secretary of Defense may have approved an expenditure of $50,000,000 for FY 1965 to cover an X level capability for system 462L. He may request an incremental cost estimate to help him decide whether the FY 1965 expenditures for this system should be increased to $75,000,000 in order to increase the capability of the system to 2X. Although the full $75,000,000 is a future cost, only $25,000,000 is an incremental cost in this particular problem.

One of the practical implications of an incremental approach to costing is that historical or sunk costs have no relevance for future decision making purposes. In the words of Hitch and McKean: "Only future sacrifices are relevant - not past. In an economic calculus 'bygones are forever bygones.'...It is only the extra or incremental cost, not historical or 'from scratch' cost, entailed by each alternative system that is relevant to the comparison[7]". As used in this sense a sunk cost refers to the historical, accounting book-value, procurement cost of an asset.

8.4.4 Context of Problem

It is important that the cost analyst recognize that the context of his problem or the level to which his analysis is directed can importantly influence whether in a particular situation an incremental cost does in fact exist.

When the problem is to optimize some design detail within the context of a given system, it is possible to neutralize or ignore many more cost elements than when inter-system comparisons are necessary. When the problem is one of intra-system analysis, the analyst and decision maker can skim over many cost areas in which the alternative configurations have equivalent cost impact whether these areas are in the realm of inherited assets, fixed supply assets, spillover effects on other systems, anticipated salvage values, high-level support costs, or direct mission costs In other words, if the decision has already been made to proceed with System X and if the total system budget has already been substantially agreed upon, analysis of the several alternative configurations can justifiably proceed incrementally by concentrating attention on the relatively few cost/effectiveness trade-offs among sensitive design areas, i.e., areas in which the various configurations differ. However, the determination relative to identical impact should not be made lightly.

However, the above restricted type of analysis is less applicable as the scope of the alternatives under consideration widens. Such widening usually occurs as one proceeds upward in the administrative hierarchy. When the scope of alternatives is widened, costs that were considered fixed and insensitive in an intra-system context become variable and sensitive. Thus, it is possible for instance, that research and development, logistics, training, and high-level support costs may be regarded as insensitive, neutral, or non-incremental in their impact when two slightly different configurations of a given Air Force X system are being evaluated exclusively against each other. On the other hand, if the analysis is broadened to rate an Air Force System X against a Navy System Y or an Army System Z, or if a command and control system is competitively evaluated against a weapon system as a means of enhancing the nation's total military posture, it becomes necessary to have a much more inclusive cataloging of costs and to give greater attention to the indirect ways in which an incremental cost can be generated, including the system non-funding costs discussed in this chapter.

8.4.5 Documentation

Careful documentation of the estimating procedure is very important when an incremental approach to costing is taken. This is true because initially most system cost estimates are prepared at lower levels of authority where a relatively narrow range of alternatives is evaluated and/or where information relative to such things as alternative users and alternative values of inherited assets, potential salvage values, possible spillovers, appropriate charges for shared assets or fixed supply assets, etc., is likely to be very limited or erroneous. Frequently, these estimates made purely for intra-system comparisons are either subsequently reviewed for validation or used as a basis for intersystem comparisons at higher levels of authority. Since some of the incremental cost assumptions of the first estimate are likely to be invalid or inappropriate for subsequent analyses, it is very necessary that the documentation of the initial estimate fully reflect how all costs were treated.

As a means of promoting this documentation it is suggested that planning type system cost estimates be prepared concurrently on both gross and net bases. The gross portion would, as far as possible, estimate the costs of a system independent of any inheritance, sharing, or side affects with or on other systems. All mission assets would be costed at their purchase price. The net portion, on the other hand, would take full cognizance of possible cost impacts that this system might have on and with other systems. Consideration would be given to the possibility of inheriting assets from other systems and, to the extent that data were obtainable, the inherited assets would be costed at their alternative use value. An attempt would be made to estimate the variable costs attributable to the system from assets or services shared with other systems. Any known or speculated repercussions in the form of spillovers and/or salvage values would also be included. If it were impossible to quantify these inherited, shared, spillover, or salvage costs, the estimate would be explicitly documented to reflect the possible or probable existence of such costs with the notation that it had been impossible to quantify them.

The advantage of this gross-net type estimate is that it would allow the office originating the estimate to make any assumptions that it considered reasonable in arriving at an estimate of the system's cost, while concurrently giving each succeeding reviewing echelon the full costing rationale employed by the lower echelon. This approach would also provide succeeding echelons with some of the basic data needed to correct mistakes in lower echelon assumptions or estimates or to realign the original estimate to fit a different context or different type of decision.

8.4.6 Specific Guidance

To promote a generally consistent and explicit application of the incremental costing principle by all cost analysts it is desirable that a set of specific operating principles be developed. Illustrative of the type of guidance referenced is the following:

a. The Air Force has provided official planning guidance to help estimate the lower level support personnel and related resource requirements for standard Air Force organizational units.[8] The specific estimating relationships provided in these published sources can be used to calculate some of the support costs referenced in this chapter.

b. In keeping with the opportunity cost or alternative use principle, an inherited asset should be costed free (no cost) to a new system if there are no alternative users for that asset.

c. If an inherited asset has multiple alternative uses, the asset should be costed at its highest alternative use value when this asset is included within the configuration of a planning type cost study.

For example, assume that an asset acquired for System A at an original cost of $5,000,000 is being released. Three (3) new military systems B, C, and D, each could make use of this asset as opposed, in each instance, to acquiring a comparable new asset. A fourth alternative is to sell the asset to a private source for $4,000,000.

System	Cost to Purchase New Asset	Cost to Refurbish & Modify System "A" Asset	"Value" of System A Asset: (i.e., Difference between the Purchase Price of a New Asset and the Refurnishing Modification Costs of the Inherited Asset)
B	4,000,000	2,000,000	2,000,000
C	8,000,000	3,000,000	5,000,000
D	10,000,000	7,000,000	3,000,000
	SALE PRICE		4,000,000

The appropriate cost to establish for the inherited asset when used in one particular employment is the value that the asset <u>would</u> have if the asset were used instead in its most productive (highest value) alternative employment. Thus, if the System A asset were made available to System B or D, it would be costed at $5,000,000 because the highest alternative use is in System C which is valued at $5,000,000. On the other hand, if the

System A asset were used in System C, it would be valued at $4,000,000 - the possible sale price to a private source, the highest alternative use value. (Note: The foregoing example is <u>not</u> intended to suggest which of the competing systems should in fact get the inherited asset. The example merely attempts to provide a systematic basis for determining how the asset should be costed if it were used in one way vs. another.)

d. If System A inherits an asset from a discontinued System B or draws such asset from the inventory of a current System C, that asset should be costed to System A at approximately its current procurement cost if such asset is on current or scheduled procurement for Systems C, D, or E. Appropriate allowance should, of course, be made for the condition of the asset that System A inherits.

e. Unless the analyst has evidence of either "idle capacity" or an unusually tight supply in the realm of designated shared assets or fixed supply assets, a new system should be charged for these assets in proportion to its use of these assets. Thus, if System A and System B are being evaluated as alternatives to satisfy a given requirement, and System A requires 5,000 military personnel of a given type and System B 500, System A should be charged approximately 10 times as much for military personnel as System B. In each case the charge per man will be that represented by the pay, allowance, and related fringe benefit costs*.

8.5 Summary

This chapter focuses on the fact that many true costs of a system decision are not fully reflected in the money flows associated with funding a system.

These system non-funding costs arise when a system inherits some of its required resources from other systems, or shares some of its required resources with other systems, or uses resources that are funded on a consolidated (non-system) basis, or bequeathes certain valuable assets to successor systems, or indirectly causes other changes in the costs of other systems.

The task of identifying and measuring these indirect costs is seriously hampered by empirical problems.

In seeking to surmount these data problems and in estimating these indirect costs, the incremental cost concept serves as a useful criterion. This principle seeks to isolate the specific additional costs attributable to a specific system decision; it rejects historical notions of cost such as book-value or sunk costs.

The chapter provided illustrative guidance for identifying and measuring the real incremental cost impact of a particular system decision.

*Some methodologists argue that the respective demands of the two systems for military personnel should not be converted to monetary terms. This position has particular relevance when there is a decided unbalance in the total supply-demand position of the asset in question.

FOOTNOTES

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[1] *Op. cit.*, pp 168-69.	137
[2] E.g., see Paul A. Samuelson, Economics, An Introductory Analysis, McGraw-Hill Book Co., (1961), pp. 471-472.	138
[3] *Op. cit.*, pp. 172	138
[4] Certain empirical studies of the private economy indicate that what-might-be-called "support" costs are both very large and also are growing in step with direct mission or operating costs. E.g., A. W. Baker and R. C. Davis Ratios of Staff to Line Employees and Stages of Differentiation of Staff Functions (Bureau of Business Research, The Ohio State University Research Monograph Number 72), 1954.	142
[5] Addressed delivered at Duke University, 26 March 1963. Charles J. Hitch, "Operations Research in the Office of the Secretary of Defense" (addressed delivered to the U. S. Army Operations Research Symposium, Durham, No. Carolina, 26 March 1963) published in the Proceedings of the United States Army Operations Research Symposium - Part I, p.9.	146
[6] For a discussion of this concept by military costing methodologists, see: Hitch and McKean, *op. cit.*, pp. 173-4, David Curry, "Costing Concepts for the Defense Programs Management System", Stanford Research Institute, Project No. IMU-3683, 1962, pp.18-22; G. H. Fisher, "What is Resource Analysis" (Seminar presented at RAND Corporation, 1963), pp. 10-11. The principle is also discussed in the general literature of economics and accounting. For instance, see: Paul Samuelson, *op. cit.*, pp. 471-72, Stigler, George, The Theory of Price, MacMillan Co. (1952), p. 96; Joel Dean, Managerial Economics, Prentice-Hall, 1951, p. 265, R. N. Anthony, Management Accounting, Richard D. Irwin, Inc., 1960, pp. 487-92.	147
[7] *Op. cit.*, p. 172, Modern accountants take the same position, e.g., Anthony, R. N., *op. cit.*, p. 488.	148
[8] E.g., AFM 172-3, USAF Planning Factors (PPF)	151

CHAPTER 9

PRESENTING THE ESTIMATE

9.1 Objectives

Basically in presenting his findings the cost analyst must be mindful of two considerations. First, it is important that the findings of the study be communicated in as meaningful and as effective fashion as possible. Second, it is necessary to take precautions to insure that the cost estimate is not misinterpreted or misused.

9.2 Problems

9.2.1 Role of Uncertainty

Most of the problems associated with presenting the results of a cost study can be traced to the tremendous uncertainties that a cost analyst has to contend with. He can rarely find out as much as he would like to know about the specifications of the requirement he is costing. Additionally, he finds it difficult to secure cost data that is either quantitatively or qualitatively adequate. Accordingly, when he derives a cost estimate for a specific system element or an entire system, the estimate is normally honeycombed with a myriad of assumptions, some more verifiable than others. Moreover, if he were to change any of these assumptions, his cost estimate would also change. Therefore, if he tries to take account of these assumptions in his cost estimate, he will end up not with one estimate, but with several or many, depending upon which assumptions prevail.

9.2.2 Tendencies to Deemphasize Uncertainty

Sometimes another problem to effective communication between the cost analyst and his client is a mutual, tacit tendency on the part of both of them to deemphasize the limitations and uncertainties in an estimate. The client as a decision maker in choosing among alternatives finds it easier to work with a single value answer and he finds it more difficult to reach clean-cut decisions if he has to take into consideration many qualifications to a cost estimate, especially if these qualifications are stated descriptively rather than quantitatively. On t'e other hand, although the cost analyst does not want to oversell the validity and reliability of his estimate, at the same time he has a human inclination not to depreciate its worth too greatly, especially if he has worked hard to estimate the cost of a difficult requirement.

9.2.3 A Political-Administrative Constraint

Another problem to objective reporting is the fact that system cost estimates are frequently generated in a semi-political atmosphere. That is most system cost estimates are prepared as one adjunct of a broader system analysis study or proposal. To win progr ming and funding approval from higher administrative and legislative echelons of authority, these proposals must be "sold" on a cost/effectiveness basis in competition with other system proposals. Therefore, when great uncertainty exists as to a system's most probable cost, the cost analyst may find that his client, if under strong pressure to sell his program, will take as his single estimated value the lower end of a range of possible values derived by the analyst. Especially in the short-run, there is relatively little that the cost analyst can do to prevent such misuse of his findings.

9.2.4 Subsequent Misuse

Many of the most serious misuses of cost estimates arise from the fact that the estimate frequently becomes a data input to later studies.

Thus, although the estimate may have been valid in its original application, it is frequently much less so in its later applications. The potential danger of such misapplication increases with the reputation of the analyst since subsequent users of an estimate are most likely to accept the estimate of a recognized expert without inquiring sufficiently into its relevance in a new situation.

9.3 General Ground Rules

In many respects the problems that a cost analyst has in communicating his findings to his client are characteristic of those existing in most adviser-client situations in the world at large. Also, certain basic ground-rules are generally applicable for improving such communication:

9.3.1 Documentation

It is very important that the cost analyst meticulously follow all of the normal rules of good reporting such as carefully stating the assumptions and qualifications on which his estimate is based and clearly defining the terms and concepts he uses. The time pressures to which the analyst is subject in completing his report, sometimes make it difficult to comply with this guidance.

9.3.2 Strategy in Reporting

The choice of the particular medium to present this supporting information is very important. If possible, the most critical qualifications should be incorporated with the estimate, itself, as an integral part of the main body of the report. If relegated to an obscure appendix of the report, they are apt to be overlooked or ignored.

9.3.3 Stressing Large and Cost-Sensitive Elements

The cost findings will, of course, be most meaningful to the client if they are expressly geared to fit his specific application of the estimate. Among other things, this means that the output tables (element estimates) and the narrative portion of the study should normally focus attention on the largest and most cost-sensitive elements.

In this regard, the study should note, if pertinent, the extent to which the system cost would be affected if the system's development and acquisition were either compressed or stretched out time-wise. For instance, certain costs, such as system management, may, to some extent, be a function of the time period over which they are spread, whereas others, such as mission equipment, may be relatively insensitive to the time factor.

Likewise, some cost element estimates are more perishable (require more frequent review and updating) than others. Certain types of equipment maintenance, where new developments in technology may be a consideration, are an example of such data perishability. Because any study may subsequently be used as a base for later studies, and sometimes without the knowledge of the analyst who did the original study, it is well to label the most perishable types of data.

9.3.4 Standardized Reporting Procedures

Standardizing cost formats and element definitions from system to system and from one costing project to another also contribute to more meaningful communication between the cost analyst and his client, especially if there are repeated contacts between the analyst and the same client on different projects.

9.3.5 Standardized Concepts

Since costing concepts, such as those used in handling inherited assets and support services, can sometimes be manipulated to achieve large differences in cost estimates, it is desirable that certain ground-rules relative to concepts be adopted in the interest of better analyst-client understanding. First, as in the case of element definitions, it is desirable that to the maximum extent possible, these concepts should be standardized. Second, it would be useful to have a succinct statement of these concepts as a standard attachment to all cost estimates. This statement should also reference more detailed methodological literature that would further explain the rationale of the concept. Finally, the main body of the narrative report covering an estimate should explicitly note and explain any deviations from these standard concepts that may have been used in that particular study.

A partial, illustrative listing of standardized costing concepts and ground-rules that might appear in a typical cost study are provided below:

1. Purposes of the Study:

   a. To estimate the total resource drain for each of the designated systems options that would be incurred during the period FY 19XX to FY 19YY.

   b. To estimate any savings, if any, that would resul. from implementing these options during FY 19XX to FY 19YY.

2. Costing Ground-Rules:

   a. This study is based on a total activity costing concept in the sense that it includes all type costs, direct and indirect, attributable to the development, acquisition, and operation of each of the designated system options.

b. However, costs are incremental in the sense that only those specific costs are included that can be identified to this particular system; i.e., only those costs that would be eliminated if it were decided to forego this system.

c. The costs specifically excluded from this estimate include the following:

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d. Costs are expressed in undiscounted, 196X dollars.

e. The time-phasing of costs is by fiscal years in which obligational authority is believed needed for commitment of funds.

f. The general system description and the appropriate schedules for each system option are contained in Section XY.

g. The estimates do not include any factor for future improvements to provide performance capability in excess of that specified in Section XY, etc.

9.3.6 Merchandising the Report

The cost analyst usually faces a problem in merchandising his findings since traditionally scientific and economic writings are dull reading to non-specialists. Considering this hazard and without sacrificing the advantages of standardized reporting procedures and formats discussed previously, it is well for the analyst to tailor his presentation to his client's background and preferences relative to such things as technical vs. non-technical exposition, the use of graphic material and visual aids, extensive tables of supporting data, etc.

9.3.7 Estimating Omitted Elements

Problems in securing data or a shortage of time to complete an estimate may sometimes oblige an analyst to omit certain relevant elements from a system cost estimate. As indicated previously, such omissions should be clearly noted in the assumptions and qualifications to the estimate. However, the client's understanding would be improved if the analyst were to give his best guess based on whatever research he had done as to the relative order-of-magnitude of the omitted costs vs. the included costs. An adjective comparison would be helpful such as the "omitted costs are considered to be minor (or major) as compared to the included costs." A quantitative estimate would be even more helpful such as "the omitted costs are roughly estimated to approximate 25 to 50 per cent of the included costs."

9.3.8 Anticipating New Applications

Similarly, because of the client's particular application, many system cost estimates are partial, rather than total, activity estimates. Future misapplications of such partial estimates could be avoided if the original estimate were to be specifically annotated with an order-of-magnitude estimate of the omitted costs that might be relevant if the original estimate were to be used for a different plausible purpose, e.g., planning vs. funding. For instance: "The costs shown for the designated airborne command system are funding oriented and should be appropriately adjusted if it is decided to use these figures in evaluating this system competitively against other systems. In this case there should be added to the total funding estimate of $ X Million a charge of $ Y Million to cover aircraft that this airborne command System A would 'inherit' or secure from weapon System B."

In this connection it is relative to reference the discussion of Chapter 2 concerning the immediate, intermediate, and ultimate clients of the cost analyst on a given costing project. Frequently, the most valuable contribution of the cost analyst to his immediate client will come through personal, verbal contact or through informal memoranda long before the final report is written, especially if the cost analyst is a member of a system design team and if he has made cost sensitivity studies to help guide the design effort. In such cases the final narrative report may be a formality that documents for the file all information that the analyst and client have exchanged.

However, even in such cases the final report is still extremely important for two reasons. Frequently, the immediate client has to submit his own broad system analysis study through several or many echelons in the process of securing official approval for the program. A carefully documented cost report is extremely valuable to subsequent echelons in making their evaluations of the system proposal.

Second, well documented cost reports on particular system studies are the basic foundation of a centralized data base system. Without such careful documentation, it is almost impossible to use past studies as a basis for future cost estimates.

9.3.9 Multi-Value Estimates

As indicated previously, many of the problems associated with presenting the results of a cost study can be traced to the tremendous uncertainties that a cost analyst has to contend with. Because of this the cost analyst in presenting his findings really has a twofold obligation to his client. One is to make an intelligent estimate as to what the cost of a new system is most likely to be. His second obligation is to provide some inkling relative to what the chances are that this best estimate will be seriously wrong, and, if it is wrong, in what direction and of what magnitude the error is likely to be. Chapter 7 in discussing uncertainty presented various methods of communicating this type of information to the client.

Chapter 7 also mentioned that the analyst could use adjective descriptors, such as "strong possibility," "very unlikely," "fair chance," etc., to convey the degree of uncertainty he felt existed in the estimate. Alternatively, he could use numerical probabilities such as .8, .95, etc., to bracket a range of estimates. Although at times the analyst may feel that his knowledge is simply not sufficiently precise to use numerical probabilities, whenever his information is adequate, he should use the numerical probability. It has been established that large differences exist among people, even among system analysts, relative to the meanings attached to adjective descriptors. In other words, the chances of misinterpretation are substantial when adjective descriptors are used.[1]

9.3.10 <u>Avoiding Pseudo Accuracy</u>

The cost analyst can also help to communicate his uncertainties to his client by the precision with which he reports his data. The practice of reporting very precise numbers connotes a pseudo accuracy because it implies a depth and precision of knowledge that in most cases simply does not exist. Thus, sub-elements should not be reported to the nearest thousand of dollars when the total system costs amount to hundreds of millions or billions of dollars. In effect the analyst should round off his figures in a way that highlights the normally tremendous uncertainties that underlie his findings rather than camouflage them.

This prescription relative to avoiding pseudo accuracy in reporting may appear, superficially at least, to contradict the suggestion made previously, to use numerical rather than adjective descriptors to communicate uncertainty. Basically, there is no contradiction. The practice should be to fit the presentation technique to fit the character of the data to be presented. Thus, if the analyst has sufficiently good information to be precise in his presentation, he should be precise. In particular, numerical statements are less subject to misinterpretation than adjective descriptors. However, if his information is not precise, he should not pretend it is.

9.3.11 Uses and Abuses of Statistics

Finally, if the cost analyst and his client are to communicate more meaningfully and if they are to use the cost findings intelligently as a tool to decision making, both the analyst and his client should become aware of the most common misuses of statistics. Such knowledge is relatively easy to acquire since in recent years a number of lucidly written books keyed to the level of the administrator and the non-professional statistician have been written on this subject.[2]

Examples of statistical areas in which the analyst and client should both be knowledgeable include the following:

Correct and Incorrect Uses of Percentages

Common Errors in Classifying Data

Uses and Misuses of Graphic Techniques

When to Use the Mean, Median, and Mode

Simple Measures of Dispersion

Dos and Don'ts of Sampling

Correct and Incorrect Uses of Index Numbers

Normal and Other Distributions

Errors of Interpolation and Extrapolation

Correlations, Cause and Effect

The Proper Role of Confidence Intervals and
How to Calculate Them

Pitfalls in Calculating Probability

9.4 Summary

The responsibilities of the cost analyst do not end when he has finally derived the estimated cost of his system. He must also communicate his findings to his client in as meaningful a fashion as possible and take whatever precautions he can to minimize a misinterpretation or misuse of these findings either by his client or by subsequent users.

The most general and probably the most important thing that the cost analyst can do to avoid a misinterpretation of his findings is to follow meticulously all of the normal rules of good research reporting, such as documenting all assumptions and qualifications and carefully defining all concepts and terms. The most important part of this information should be incorporated into the body of the report rather than relegated to an appendix where it would more likely be overlooked.

All tabular and narrative material should be expressly geared to answer the specific questions that follow from the client's intended application of the estimate and to highlight the largest and most sensitive cost elements.

Standardized cost formats, definitions, and concepts from system to system and from project to project will minimize potential areas of confusion and misunderstanding.

To the extent that he can, the cost analyst should include in his study an order-of-magnitude adjustment that would be applied if his estimate were to be used for other different, but related, purposes.

Ranges of estimates with a probability distribution attached to various intervals of the range, as opposed to a single expected value estimate, are a useful means of conveying uncertainty to the client.

The total system cost estimate plus that of individual elements should be rounded appropriately to highlight, rather than camouflage, the uncertainties pervading the data underlying the estimate.

FOOTNOTES

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[1] An SDC study revealed amazing differences in the meanings (numerical probabilities) associated with common verbal phrases such as "highly probable," "fair chance," "somewhat unlikely," etc., S. C. Lichtenstein and J. R. Newman, "Empirical Scaling of Common Verbal Phrases Associated With Numerical Probabilities," System Development Corporation, Technical Memorandum 1150/002/00 (28 June 1963). 164

[2] For instance: W. U. Reichman, Use and Abuse of Statistics (Oxford University Press, 1961); Hans Zeisel, Say It With Figures (Harper & Row, 1957); W. A. Wallis & H. V. Roberts, Statistics, A New Approach (The Free Press, 1959) Ch. 2 & 3. 165

CHAPTER 10

USING THE COST ESTIMATE AS A DECISION-MAKING TOOL

10.1 Purpose

This study has sought primarily to show how the explicit, non-personal methodology so successfully used in the hard sciences can be employed to estimate more accurately the costs involved in developing, acquiring, and operating a military system. The present chapter is in a sense an epilogue to the previous chapters in that it discusses a broader and perhaps more basic issue, namely, where do the responsibilities of the analyst begin and end? In other words, do the potentialities for systematic analysis end with the derivation and presentation of the cost estimate? Must the larger problems of choosing the system's goals and selecting the preferred alternative for meeting these goals be left entirely to the intuitive judgment of the client, or can the analyst help the client *systematically* to resolve these larger problems?

In recent years the movement to apply systematic analysis to the total military system decision problem has proceeded rapidly under many guises - operations research, system analysis, management science, etc. Currently a frequent appellation for this type of methodology is cost/effectiveness analysis. Our objective here is not to cover the methodology of cost/effective analysis; it would take a full-length book to do that adequately. Rather, the objective of this chapter is to explore briefly in what ways, direct and indirect, the influence of the cost analyst may be felt on the client's choice of goals and system alternatives to meet these goals.

It should be stressed that the discussion that follows is aimed more at being selectively prescriptive rather than generally descriptive. In other words, it is not intended to recapitulate the responsibilities that historically cost analysts have had.

Thus, frequently either the characteristics of the problem being analyzed or the administrative ground-rules of the project prevent the cost analyst from providing the type of service to his client described below. In some cases the client knows exactly what his goals are, he has completely identified his possible system alternatives, and the system study shows that one alternative is so clearly superior to the others that the client needs no sophisticated methodology to help him make his choice. In other cases these matters may not be so clear-cut, but either limitations of time to complete the project or a client's preference to keep these responsibilities entirely unto himself limit the cost analyst's contribution. The following discussion applies when neither these inherent or contrived constraints prevail.

10.2 Establishing Objectives

10.2.1 Firming Up Goals

As a member of an inter-discipline system analysis team the cost analyst can sometimes contribute importantly to establishing the goals of a project. In the first place, the client frequently has only vague, and sometimes conflicting, notions regarding his requirements when he first requests an advanced systems study. It is part of the analyst's responsibility to extract from the client and to develop with the client a definitive, consistent statement of these goals and to translate these generally stated mission goals into specific performance attributes.[1]

10.2.2 The Role of Analysis

This translation demands a high level analytical capability for several reasons. One is that in the military systems field, especially electronic command and control systems, the system performance parameters are generally expressed in nebulous, qualitative terms such as flexibility, growth potential, consistency of response, etc. These terms must be defined meaningfully both within the context of the particular mission and also consistently to reflect the higher level national goals that the particular mission contributes to. Second, a major responsibility of the analyst is, wherever possible, to find means of measuring quantitatively each of these performance characteristics so that the various system alternatives may subsequently be rated on how well they meet these requirements.

10.2.3 The Role of the Cost Analyst

In practice the stimulus to make these careful definitions and translations frequently originates with the cost analyst's persistent efforts to ascertain the details of the system that he is to cost (see Chapter 3). This prodding by the cost analyst may, for instance, oblige the military planr r and the other members of the system design team to more concretely crystalize their notions relative to thresholds (minimum acceptable levels of performance) for each of the relevant attributes of total system effectiveness, and also to speculate how much relative value they place on successive increments of performance above these thresholds.

Moreover, if the cost analyst has participated in many system analysis projects in the past he will have acquired some finesse in extracting and formulating these definitions and translations and thus can actively contribute to the process. Again in practice, an experienced cost analyst sometimes has major responsibility for defining, as well as for costing, certain support and related requirements.

10.2.4 The Impact of Opportunity Costs

In another important way the costs analyst's findings can contribute importantly to establishing the client's goals. This contribution is exerted through the limited-resources, opportunity-cost principles discussed in Chapters 1 and 8. To reiterate, in the deepest practical sense, no goal has an intrinsic value unaffected by the resource requirements (costs) associated with satisfying the goal. Frequently, if the client had initially established his goals with no knowledge or seriously erroneous knowledge relative to their resource implications, the cost analyst's initial findings are likely to prompt substantial revisions in these goals. Thus, an anti-missile defense is likely to rank high on the nation's list of practical military system objectives if such a defense could be achieved for $500 million. The relative ranking of such a goal on a list of practical military system objectives, as opposed to a "nice-to-have" wishing list, is likely to fall rapidly if it is found that such a capability would cost $500 billion. This principle applies with equal force whether one is establishing objectives and requirements within the context of a given system or mission, or whether one is deciding at the broadest possible level what our national goals should be. The choice of goals and the costs associated with achieving these goals are inextricably bound together.[2]

10.3 Establishing Alternatives

10.3.1 Eliminating Dominated Alternatives

The cost analyst not only can assist in establishing the client's objectives, he also can participate in establishing system alternatives to meet these objectives.

In the first place, since the cost analyst is responsible for working up the costs for each of the initially conceived system alternatives, he participates on a working level in spelling out the cost/effectiveness trade-offs of these alternatives. Two consequences flow from this trade-off analysis. One, as suggested in Section 10.2, the client may revise some of his initial constraints and performance thresholds when he sees the opportunity costs posed by the cost/effectiveness analysis. Second, such analysis may automatically - with little decision action on the part of the client - identify and eliminate from further consideration certain dominated alternatives. (Alternative A dominates Alternative B if A is superior to B in at least some of the relevant system performance characteristics, is inferior to B in no relevant performance characteristic, and costs no more (or less) than B.)

10.3.2 Drafting New Alternatives

A second major responsibility that the cost analyst and other members of the system analysis team have is to see that the client is fully aware of all of his alternatives. In this connection they may participate in drafting new alternatives not originally proposed or conceived by the client. This need to establish new alternatives derives from the fact that normally after the analysis has eliminated from further consideration the dominated alternatives, there remain several or numerous alternatives for which there exists no clear-cut dominance. In other words, alternative X may provide superior performance to alternative Y in one or more characteristic(s), but provide inferior performance in some other characteristic(s) including cost. Before the client attempts to choose one of these alternatives, the system analysis team may ascertain whether some new alternative(s) can be drafted which will combine some of the best features of alternatives X and Y without offsetting disadvantages.

In the drafting of such alternatives, the cost analyst is again intimately involved. He will make cost sensitivity studies that will be used to reorient the design effort. These studies will ascertain the relative sensitivity of total system cost to selective changes in the values of each of the major system performance and design characteristics. One result of these cost sensitivity studies may be to reclassify some of the original undominated alternatives into a dominated status. To take a hypothetical example, a reanalysis - including cost sensitivity studies - could develop a new alternative "C" that would dominate two alternatives A and B that originally were among the undominated alternatives in a first-pass cost/effectiveness analysis:

Alternatives	Performance Characteristic (Index)		Total System Cost ($M)
	X	Y	
	(Original Analysis)		
A	100	70	100
B	75	80	105
	(New Analysis)		
C	100	80	100

10.4 Selecting The Preferred Alternative

10.4.1 The Problem of Incommensurables

Unless cost sensitivity studies and other design activities have succeeded in discovering one system alternative that dominates all others, the client must decide which alternative on net balance he prefers. This decision is difficult bec se he has to make a choice among what system analysts call incommensurables, elements having no common basis for comparison. Thus, in the case of a warning system he may have to decide whether he prefers System A which will provide a 5 minute warning of an enemy attack with a 99% reliability (will provide correct information 99% of the time) or System B which will provide a 10 minute warning time with a 90% reliability. The difficulty of the choice is, of course, increased if Systems A & B also differ in other important performance areas and in total cost, and for technical or other reasons it is not possible to develop another alternative that will combine the advantages of A and B without offsetting disadvantages.

10.4.2 History, Judgment, and Values

This matter of selecting a preferred system among several or numerous undominated alternatives is one of the most important and most difficult aspects of the military system analysis process. Historically, it is the area in which intuitive, subjective factors - judgment, experience, etc. - have dominated the decision-making process. Many authorities believe that such factors will (and should) always prevail over systematic analysis because such decisions are intimately tied up with "values."

10.4.3 The Criterion Issue

Other authorities, however, believe that systematic analysis can do much to help the client better apply his experience, judgment, and value standards. Hitch and McKean, for instance, state that "...the selection of an appropriate criterion is frequently the central problem in the design of an economic analysis intended to improve military decisions."[3] In other words, they regard it as one of the economist's responsibilities to contribute importantly to the design of criteria on the basis of which one system is chosen over another.

Although methodologists (economists, system analysts, operations researcher analysts, etc.) have not developed and agreed upon a set of universal criteria applicable to all situations, they are in substantial agreement that certain criteria are better than others and that some of the criteria frequently used by military planners in the past are basically invalid.[4] In effect, this is to say that even with the present undeveloped state of knowledge, systematic analysis has something to offer in this really pivotal area of deciding upon what basis a client will evaluate and select one system alternative over another.

One example may be cited: Military planners have sometimes selected a preferred system on an effectiveness/cost ratio basis. They have picked the system which offered the greatest amount of effectiveness per dollar cost. This seemingly plausible criterion is basically deficient in that it implicitly assumes a linear relationship between cost and effectiveness, i.e., that an alternative which is superior at one level of performance will be superior at all levels. By ignoring the level of performance decision, this technique would, under some conditions, lead to buying much more performance than needed to accomplish a mission and, under other conditions, provide much less than a minimum required level of performance, or in the words of Hitch and McKean (op. cit., p. 166) to provide "... a system that would invite and lose a war inexpensively."

10.5 Summary

Figuratively speaking, there is no end to the possible applications of explicit, systematic analysis to the problem of military system choice. From the setting of mission objectives, the drafting and evaluating of system alternatives to meet these objectives, the elimination of dominated alternatives from further consideration and the drafting of new alternatives, to the critically important creation of criteria to evaluate the undominated alternatives and to select the preferred alternative, the system analyst, including the cost analyst as a member of an interdiscipline system analysis team, has a large role to play. Whether and to what extent this role is activated on a particular project is a function, on the one hand, of the characteristics and constraints of the problem being analyzed and, on the other hand, of the administrative ground-rules governing the project.

FOOTNOTES

Pag

1. This point is well stated by C. J. Hitch, presently DOD Comptroller, in "On the Choice of Objectives in System Studies," RAND P-1955, (1960). 17(

2. Hitch and McKean in numerous writings have lucidly established this point. For instance, Hitch op. cit.: p. 11, "The feedback on objectives may in some cases be the most important result of our study. We have never undertaken a major system study at RAND in which we were able to define satisfactory objectives at the beginning of the study." (Emphasis supplied - M.V.J.) 172

3. *Op. cit.*, p. 158. (Emphasis supplied - M.V.J.) 17?

4. Hitch and McKean, *op. cit.* devote approximately 30 pages (pp. 158-87) to this subject. 17(

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13. ABSTRACT

This document presents a generalized, integrated conceptual approach to the major steps involved in estimating the costs of a military system. The approach is generalized in the sense that the document identifies the common methodological problems and tasks involved in costing all military systems. The approach is integrated in the sense of discussing the entire process of costing a system from beginning to end and in showing the methodological relationships of each sequential step to preceding and subsequent steps. The approach is conceptual in the sense that fundamental principles are stressed as opposed to a catalog of resource costs and estimating relationships or a case book detailing the specific procedures used to cost particular systems in the past.

Notwithstanding its conceptual orientation, the approach in this study is task oriented in the sense that discussion centers around such highly practical questions as the following: what an analyst should learn about the client's intended application of the estimate and about the details of the system he is to cost before he begins the costing task itself; the criteria an analyst can use to help him realize the greatest benefit from the limited time he normally has available to make the estimate; the types of activities and resources he should cost and in what detail; the types of data he should seek as a basis to cost such activities and resources, and the sources from which he should try to collect these data; how he should proceed to evaluate and synthesize his data inputs to arrive at his system cost estimate; how he should present the details of his findings so that they will be most meaningful to his client and not be misinterpreted.

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